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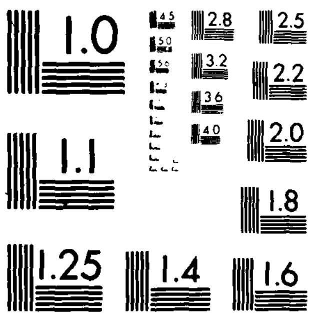

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NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

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DESIGN CALCULATION PROCEDURE FOR PASSIVE SOLAR HOUSES AT NAVY INSTALLATIONS IN EAST COAST REGIONS WITH TEMPERATE CLIMATE -- VOLUME II

October 1981

An Investigation Conducted by
New Mexico State University
Las Cruces, New Mexico

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These reports present design calculation procedures for passive solar houses. A "worksheet" approach is used in that the user may work through an example passive solar design by following the text in the report. Included are tables for heating degree days, solar heat gains, building R factors, orientation factors, roof overhang designs, etc. Performance is

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calculated on a monthly basis. The reports are presented for five (5) geographical regions with content and text format similar, differing only in the appropriate regional factors. This volume gives appropriate designs for Navy installations in East Coast regions with temperate climate.

ACKNOWLEDGEMENT

This design calculation procedure was originally developed for the State of New Mexico under a research project funded by the New Mexico Energy and Minerals Department (Grant #78-2228, Monika Lumsdaine, Principal Investigator) and published as Report NMEI 22-SA by the New Mexico Energy Institute at New Mexico State University. It has been tested and used extensively in workshops sponsored by the New Mexico Solar Energy Institute at NMSU. Navy Contract #N62583/79M R585 was awarded to the NMSEI to adapt the procedure with supporting information for use in other geographical locations in the United States, particularly in regions with Navy installations. Marilyn A. Chase, Mechanical Engineering student (NMSEI), has assisted in assembling data and reducing it to graphical form. Ed Durlak, Naval Civil Engineering Laboratory, Port Hueneme, California, has carefully reviewed the draft of this manual and made many suggestions to make the procedure easier to apply by Navy personnel.

M.L.
E.L.

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1. INTRODUCTION

The simple design method presented here has been developed in response to the following needs and objectives:

(a) This calculation procedure can be used by designers, contractors, and owner/builders working on plans for passive solar houses. The method is simple enough for people to apply who do not have an extensive background in science, engineering or mathematics. All necessary supporting data is provided.

(b) The procedure can be used to evaluate the performance of various retrofit design options.

(c) Design calculations for DOE and HUD solar projects are quite complicated. The procedure provides a "primer" to familiarize interested people without previous experience with the basic steps involved in heat load calculations for solar applications.

(d) Building inspectors, FHA, and other financial institutions may require heat load calculations, especially if the planned building does not include a full-size backup heating system.

(e) The design calculation procedure also provides a uniform format for reporting and evaluating the performance of existing passive solar homes in comparison studies.

Since different climates call for somewhat different approaches to passive solar design, five different variations of the original manual have been prepared:

Vol. I - COLD CLIMATE (includes Aleutian Islands, Alaska, the New England Coast from New Haven, Connecticut to Brunswick, Maine, and the southern Great Lakes region around Chicago, Detroit and Cleveland).

Vol. II - TEMPERATE EAST COAST CLIMATE (includes the northern Philadelphia - Washington region and the Atlantic Coast from Norfolk to Charleston).

Vol. III - WARM, HUMID CLIMATE (includes Florida, Hawaii, and the Gulf Coast).

Vol. IV - PACIFIC NORTHWEST CLIMATE (includes only areas west of the Cascades from Seattle, Washington, to Portland, Oregon).

Vol. V - WARM CALIFORNIA CLIMATE (includes the coast from Oakland to San Diego as well as high and low desert areas).

It is assumed that the designer has a basic knowledge of passive solar mechanisms and their operational characteristics. A brief summary is given in the following chapter, and a number of useful reference books are listed at the end of this manual.

The calculation procedure is divided into several steps with corresponding worksheets and supporting data. An additional blank set of worksheets easily removable for xeroxing is attached.

This simple procedure should be especially helpful during the early design phase to evaluate the effect of various design options and combinations and again in checking out the final design, and to determine the approximate auxiliary heat load. The procedure is best applied to direct gain, Trombe walls (mass or water), solar roofs and combinations of these. Sunspaces that are an integral part of the house fall under direct gain; attached solar greenhouses with a large amount of exposed surfaces require an additional set of calculations for the greenhouse alone, with the net heat gain then added to the house calculations. Using a simple hand calculator or slide rule will save time.

2. REVIEW OF DEFINITIONS

Solar systems for heating (and cooling) can be divided into two basic categories: active (mechanical) systems and passive (natural) systems. Active systems need some energy input outside of solar to operate. This so-called "parasitic" power requirement can, in some applications, be so large that none or very little net savings will result by using the active solar system. This is true, for instance, in smaller intallations of lithium-bromide absorption solar cooling. Active systems resemble in their application conventional HVAC systems in that they consist of a number of components that can be installed after the structure has already been erected. Passive (natural) systems operate without mechanical components or parasitic power input by making use of the natural laws of heat transfer and the properties of building materials to store or transmit solar energy to such an extent that the entire building becomes a live-in solar collector. Thus, passive systems are built right into the structure. The completed building and passive solar system(s) are quite easy to operate since many controls are daily or seasonally automatic. The passive system(s) must be designed and calculated carefully for satisfactory performance, because mistakes will be very difficult to correct once they are built into the house. On the other hand, many options exist that make the design quite flexible, and some features do not have to be fixed until the house has been lived in for a year or so---the building has to be fine-tuned, so to speak. The performance of a passive system can be augmented with the addition of blowers or fans to obtain better heat distribution. Technically speaking, passive systems that use mechanical energy to transport heat around are known as hybrid systems.

Table 2.1 lists definitions for common heat transfer terms used in this manual. The primary passive solar heating methods are direct gain, thermal storage wall (Trombe or water wall), and sunspace (greenhouse); roof ponds, thermosyphon systems and hybrid solar roofs involve more hardware and are thus somewhat more complicated. The heat transfer mechanisms involved between the sun, the living space and the storage mass are very subtle and closely interrelated; thus the building must be designed carefully, and the interaction between the passive solar system(s) and the people living there must also be considered.

TABLE 2.1

Definition of Heat Transfer Terms

HEAT is the sum of the kinetic energy of all molecules in a mass of material due to the random molecular jostling motion.

TEMPERATURE is the intensity of heat (or molecular velocity) and does not depend on the amount of mass present.

CONDUCTION is heat moving from a warmer to a colder region in the same substance; this type of heat transfer takes a definite amount of time and depends on the conductivity of the material.

CONDUCTIVITY is a measure of the rate at which heat is conducted through a slab of material whose two sides are kept at a constant temperature differential.

CONVECTION is the circulatory motion of a fluid (liquid or gas) caused by temperature differences without the use of mechanical devices. Heat transfer by convection also takes a certain amount of time. It is sometimes called natural convection to distinguish it from forced convection.

FORCED CONVECTION occurs when air or liquids are made to circulate with the aid of fans/blowers or pumps.

RADIATION is the transfer of heat by electromagnetic waves from an emitter at higher temperature to an absorber at lower temperature. Conversion from radiation to heat occurs when the radiation is absorbed by a substance. This heat transfer occurs practically instantaneously. The radiation properties (emissivity and absorptivity) and temperatures of the emitting and absorbing surfaces will determine the rate of heat exchange between them.

SENSIBLE HEAT is the heat involved when the temperature of a storage material is raised or lowered.

LATENT HEAT OF FUSION is the heat involved in changing a substance between the solid and liquid states.

SPECIFIC HEAT is the quantity of Btu's which can be stored in a material per pound and per degree Fahrenheit.

HEAT CAPACITY is the quantity of heat that can be stored in a cubic foot of material; it is the specific heat of the substance multiplied by its density.

CONTINUED

Table 2.1 Continued

RADIANT INTENSITY depends on the size and temperature of the emitting surface and the proximity of the absorber.

REFLECTIVITY is a property of materials to "bounce-off" radiant energy instead of absorbing it.

ABSORPTION is the phenomenon of conversion of electromagnetic waves of radiated energy to heat by the surface of a material. From the surface, the heat is then transferred into the material by conduction.

TRANSMISSIVITY is the property of certain materials to let radiant energy pass through without absorbing all of it.

THERMOSYPHONING is a term traditionally applied to mechanical systems that use the natural rise of heated gases or liquids for heat transport.

AUXILIARY SYSTEM is the backup system or conventional space heating or water heating system used to supply energy during periods of completely cloudy weather when the solar systems cannot supply all the energy demanded.

INSULATORS are materials with a low conductivity. These materials are said to have a high resistance to heat flow by conduction and are identified by a high R-value.

1 Btu (BRITISH THERMAL UNIT) is the heat necessary to raise one pound of water by one degree Fahrenheit.

LIVING SPACE as defined and used in this manual denotes any space in the house occupied by people for a variety of activities such as cooking, heating, sleeping, bathing, play and recreation, etc.

U-VALUE (or the coefficient of heat transmission of a material or combination of materials) is defined as the rate of heat flow per square foot per degree Fahrenheit temperature between air on the inside and air on the outside of a wall, roof or floor. It is the reciprocal of R, the thermal resistance of a material. Note that R-factors can be added, whereas U cannot. To calculate the U-value of a combination of substances, first find the total R-value by adding the individual R factors, or $R_1 + R_2 + R_3 + \ldots = R_{Total}$ then $U = \frac{1}{R_{Total}}$.

The main heat transfer mechanisms involved during the day and night for the different types of passive solar heating systems are indicated in Figures 2.1, 2.3, 2.4 and 2.6.

2.1 Direct Gain

The simplest and most widely used passive solar heating system is direct gain. It consists of large, south-facing windows combined with a heat storage mass in the room. If the system incorporates operable windows and movable shading and window insulation, a variety of ways to control the level of comfort, both during summer and winter, are provided. The daily temperature fluctuations in the living space are somewhat higher than for a Trombe wall system, and glare may be a problem under certain circumstances. The solar greenhouse is also an application of the direct-gain method; here the daily temperature fluctuations are quite large because glazing is increased and storage mass is relatively small in order to yield excess heat for transfer into the living space adjacent to the greenhouse. Maximum room depth for effective direct gain is 2½ times window height (from floor level) [1]. This will also give good daylighting. The basic schematic is shown in Figure 2.1.

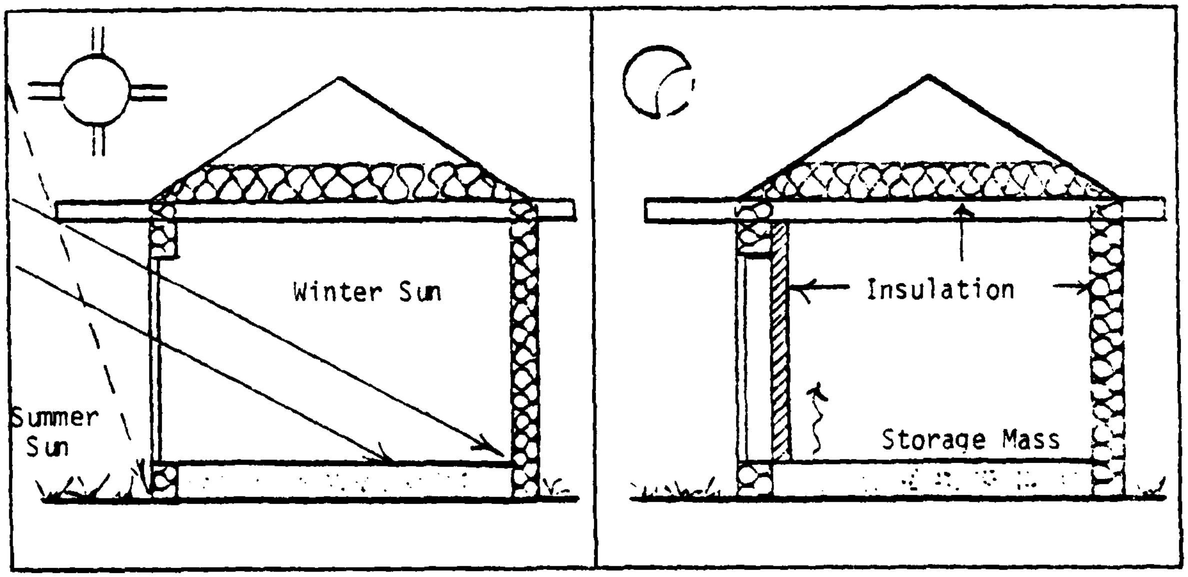


Figure 2.1 Schematic of the Basic Direct Gain Passive Solar Heating System (Winter Operation)

A great degree of freedom exists in the placement of the storage mass in direct-gain systems, as shown in Figure 2.2. The storage mass can be heated either by sunlight striking it directly (preferably a considerable portion of a winter day), or by solar-heated air passing over it, or by reflected radiation from other surfaces in the room. If the storage surface is struck directly by

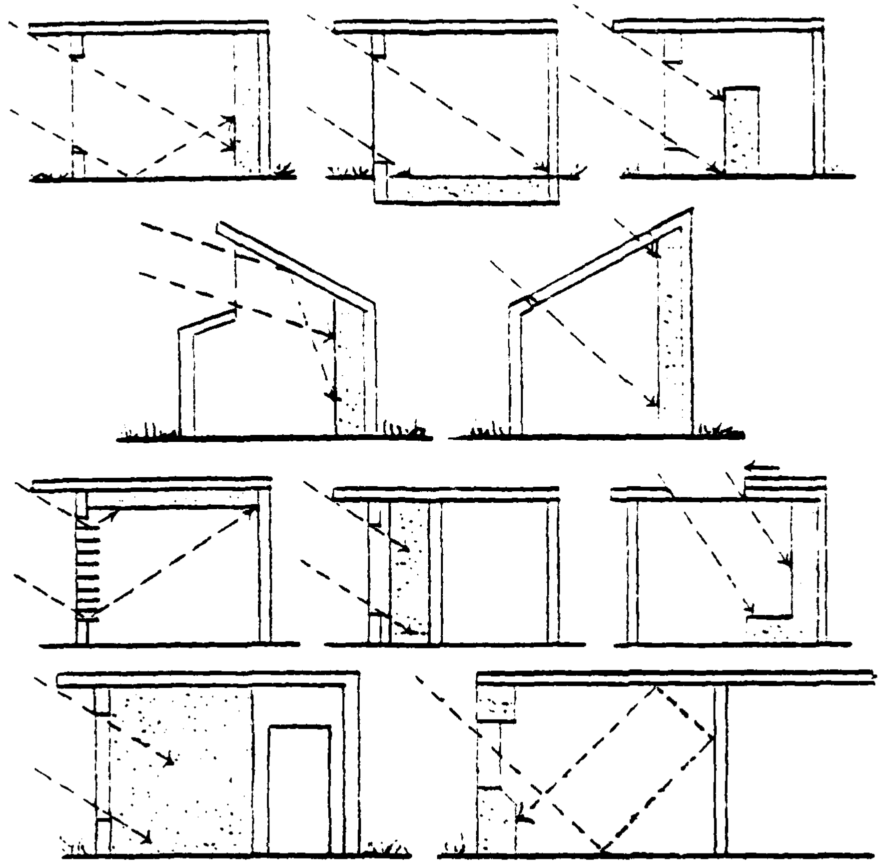


Figure 2.2 Examples of Direct-Gain Window and Storage Locations

sunlight, its performance is increased if its color is dark (see Table 2.2). If the mass only absorbs radiation bounced off from other surfaces, the color does not matter, but the volume required is about 4 times larger than if it received sun all day long in order to achieve similar comfort conditions.* When room temperature falls below that of the storage mass, the storage will begin to reradiate this energy. Some heat transfer also takes place through barely noticeable convective air currents. Attention must be paid to provide sufficient surface area for efficient storage. The amount of storage also

*For example, if storage mass in the sun increases by 20° F from morning to mid-afternoon, air temperature in the room will rise by about 10° F. For a 10° F air temperature rise, storage mass not receiving direct solar radiation will increase by only 5° F; thus the volume to store an equivalent quantity of heat must be 4 times larger.

depends on the climate. In areas with much winter sun, sufficient mass to store heat over 2-3 days is a good idea. This is also true for places that experience large night-day temperature fluctuations in the summer. Places with cloudy winters and/or humid summers should have storage sufficient only to heat the home through one night.

TABLE 2.2

Absorptivity of Building Materials and Paints

Material/Color	Absorptivity
Slate Composition Roofing	0.9
Graphite	0.84
Red-Brown Linoleum	0.84
Asbestos Slate	0.81
Dark Colors	0.8
Gray Soft Rubber	0.65
Concrete	0.59
Red Brick	0.55
Medium Colors	0.5
Cork	0.45
Light Colors	0.2
Aluminum Paint	0.18
White Tile	0.18
Anodized Aluminum	0.15
Wood, Paper, Cloth, Gypsum	0.1 - 0.45

The principal storage materials are water or different kinds of masonry: adobe, brick, sand or cement-filled concrete block (slump block or cinder block), poured concrete, rammed earth, stone, rock, or tile. The heat transfer and storage characteristics of masonry materials do not vary by much; therefore, the choice can be based on local availability, cost, structural considerations and local building code requirements. For storage over several days, masonry is more effective than water. Because of internal convection, water storage containers release heat more quickly than do 2 ft thick masonry walls, for example. From a construction standpoint, it is also easier to incorporate larger amounts of masonry storage than oversize water containers. But because water requires only about 1/3 the volume of masonry to store an equal quantity of heat, water may be preferable in retrofit applications (if existing construction is able to support this load). Table 2.3 lists a number of possible water containers for passive solar heat storage.

TABLE 2.3
Water Containers for Passive Solar Heat Storage
(From D. A. Bainbridge, "How to Build a Water Wall," SOLAR AGE, Vol. 4, No. 8, Aug. 1979, pp. 38-41).

TYPE	SOURCE	SIZE	VOLUME	COST/GAL.	INSTALLED COST	NOTES
Tanks*	Local welder	Any (1-1/2x3x6 3x6 ft recom.)	Any	30¢ to $1.50	50¢ to $1.50	Aesthetically appealing, easy to install, effective.
Drums*	Drum manufacturer, chemical supply, etc.		30 or 50 gal.	10 to 45¢	20¢ to $1.50	Cheap, readily available, hard to clean, must be stacked carefully.
Culverts*	Pipe supply, scrap yards	12 in. + diam.	Depends on length	30 to 50¢	50¢ to $1.50	Tough, attractive to some, help where floor space is tight. Make sure installation is seismically safe.
Kalwall Cylinders	Kalwall	12 in. & 18 in.	Depends on length	40¢ to $1.45	50¢ to $1.75	Translucent, easy to install and move, easy to damage. Best where traffic is light.
PVC Pipes	Agricultural supply	6 in. & 12 in.	Varies	10 to 20¢	30¢ to $1.20	Light, durable, heat transfer not as good. Must rack or brace to mount.
Glass Bottles	Various	Varies	Up to 10 gal.			Cheap, readily available, must seal carefully, moving difficult.
Steel or Aluminum Pipes*	Scrap yard or supply	6 to 12 in.	Varies	10 to 40¢	30¢ to $1.50	Readily available, time-consuming to build racks, hard to clean.
Modules	One Design	Steel or fiber-glass		$1.00/gal. est.	$1.50/gal.	Easy to install and ship. Good potential for cooling.
Tanks* or Modules	Tabline	46 in. x 4 ft x 16 in.	90 gal.	$1.00+/gal. est.	$1.50/gal.	Easy to retrofit, good interface with stud construction.

* May required corrosion inhibitor. Also cap and container should be of the same material to prevent leaks.

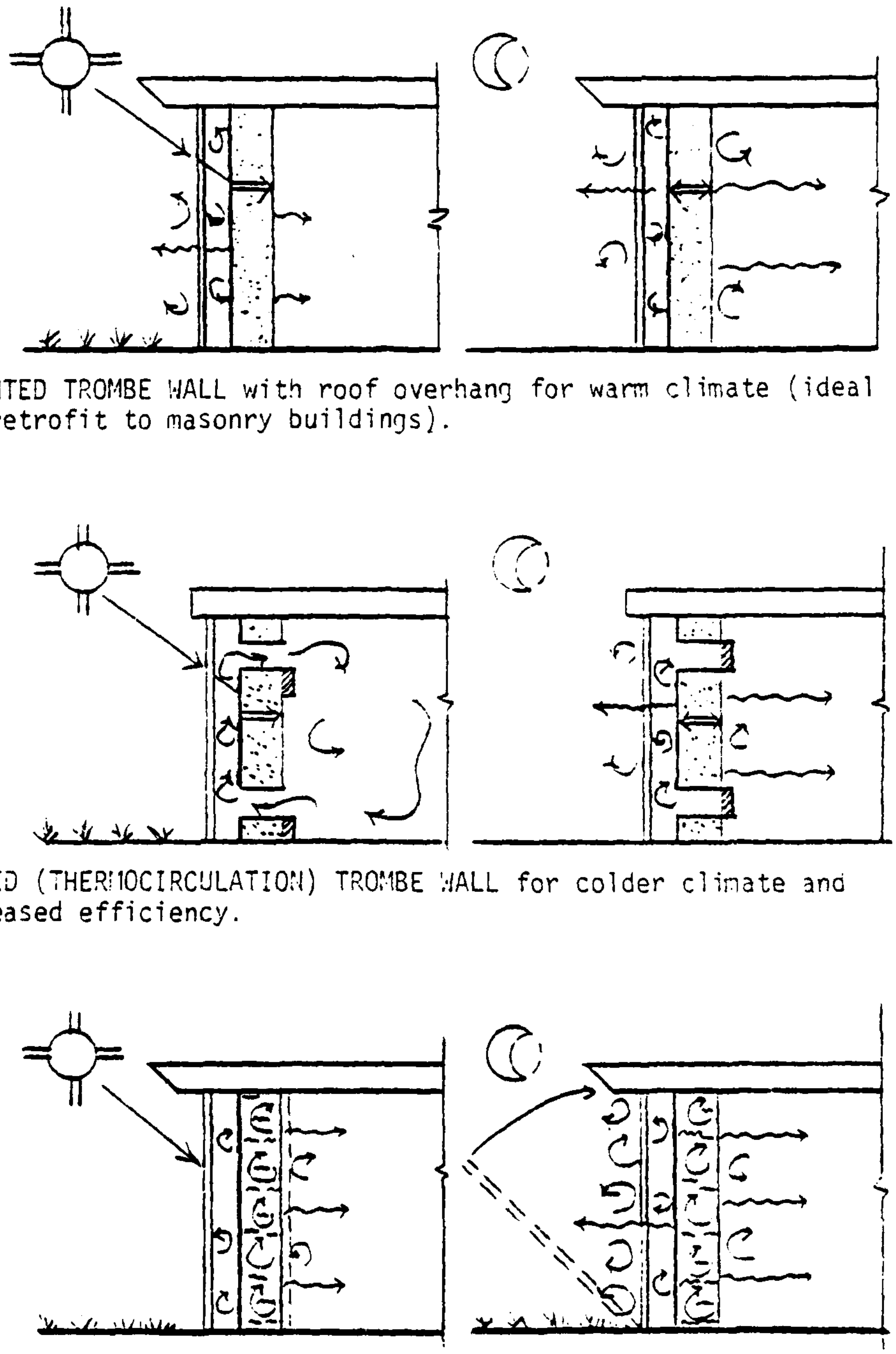
2.2 Thermal Storage Walls

The thermal storage wall, since it is located between the sun and the living space, is an indirect passive solar heating system. The three main types of thermal storage walls (vented and unvented Trombe wall and water wall) are combined collector/storage passive heating methods and have somewhat different performance characteristics since the heat transfer mechanisms for each type vary, as indicated on Figure 2.3. Additionally, performance is also influenced by wall thickness, the conductivity of the material, and insulation. It is highly recommended that double glazing (two sheets of glass or plastic) be used to reduce heat losses from the storage wall to the outside unless night insulation is provided. The wall surface facing the sun is painted dark (though not necessarily black) to increase absorption.

Rooms heated with thermal storage walls should not be more than 20 feet deep [1]. Masonry has the advantage of providing a structural function (load-bearing wall); water, on the other hand, requires less volume. The Passive Solar Energy Book by Edward Mazria, Rodale Press, Emmaus, Pennsylvania, 1979, and the Thermal Storage Wall Design Manual by Alex Wilson, New Mexico Solar Energy Association, P. O. Box 2004, Santa Fe, NM 87501 ($4.75) give much information on the thermal storage wall, including sizing and construction details.

2.3 Sunspace (Solar Greenhouse)

The sunspace (solarium or greenhouse) system is a combination of direct gain and Trombe wall, as shown in Figure 2.4. The storage mass in a greenhouse is sized to keep the plants from freezing during cold winter nights. The daily air temperature swing in the greenhouse can be as much as 40°F, with the excessive heat available for heating the living spaces adjacent to the greenhouse. In warmer climates, sufficient and correctly placed vents must be provided to prevent overheating in the summer. Figure 2.5 shows the schematic of a northside greenhouse retrofit possible for warmer climates. A south greenhouse retrofit is suitable even in cooler climates (if night insulation for the glazing is provided).



(a) UNVENTED TROMBE WALL with roof overhang for warm climate (ideal for retrofit to masonry buildings).

(b) VENTED (THERMOCIRCULATION) TROMBE WALL for colder climate and increased efficiency.

(c) WATER WALL with movable interior and exterior insulation for heat transfer control and increased efficiency. (Efficiency also depends on container surface material.)

Figure 2.3 Heat Transfer Mechanisms of Thermal Storage Walls

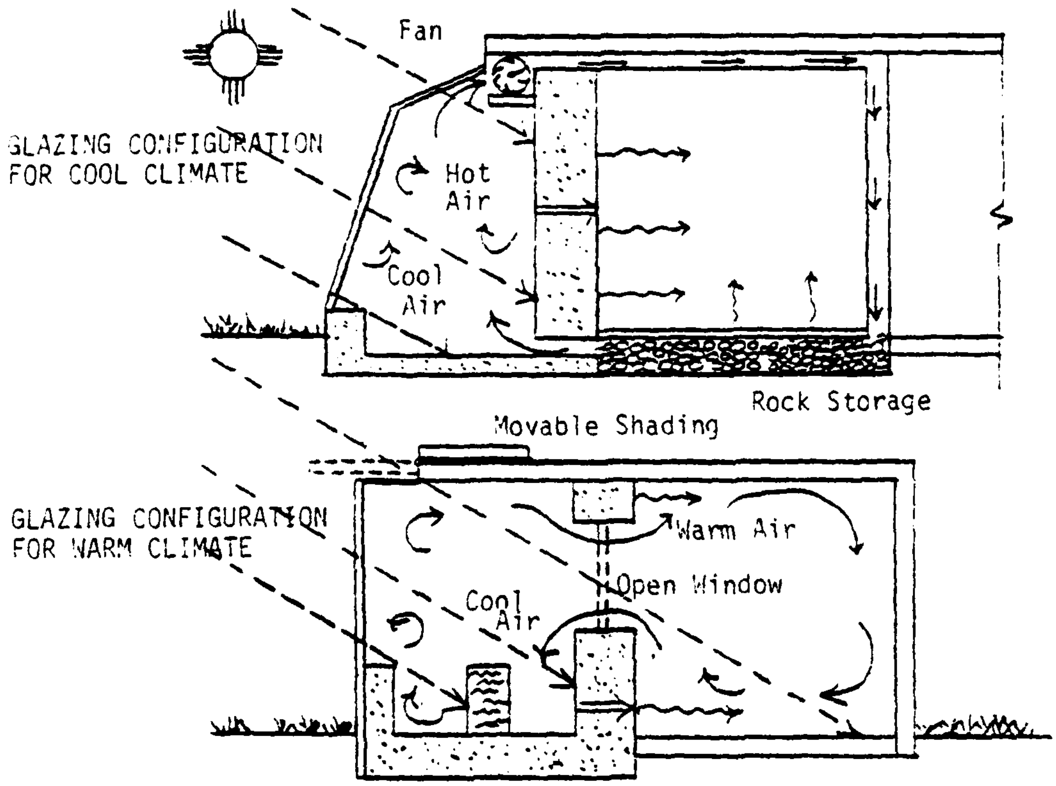


Figure 2.4 Heating of Living Space with Solar Greenhouse

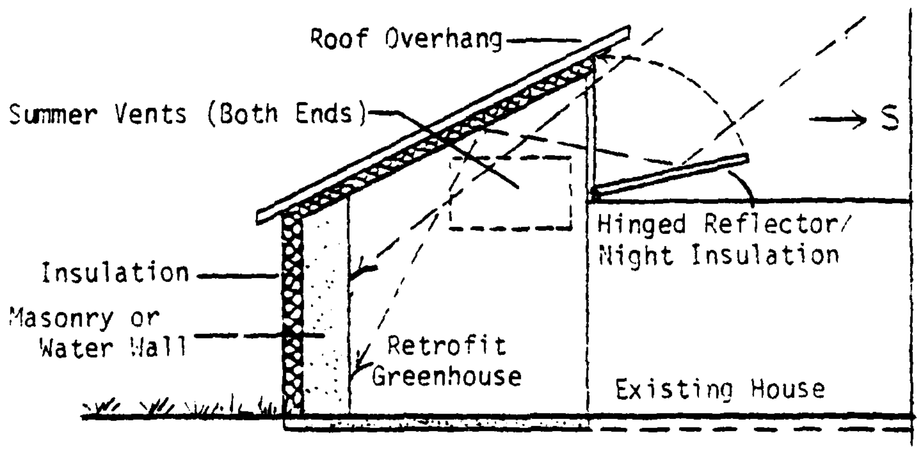


Figure 2.5 Schematic of North-Side Greenhouse Retrofit

2.4 Other Passive/Hybrid Systems

A number of other passive/hybrid systems have been developed for residential applications. These are somewhat more complicated to design and build by contractors without previous experience, or they are applicable to limited climatic regions for best performance. Among these systems are the roof pond developed by Harold Hay for Southern California, the hybrid solar roof (Southern New Mexico) and the natural convective loop system (thermosyphon) which more closely resembles an active solar system since it employs a bank of solar collectors. Schematics of these systems are shown in Figures 2.6, 2.7, 2.8 and 2.9.

Much research and development work is currently underway with new heat storage materials. In the passive methods described above, the usual heat storage medium is either masonry or water (or sometimes a combination of both); these media store sensible heat by undergoing an increase in temperature. Phase-change materials, on the other hand, make use of latent heat of fusion to store large quantities of heat without much temperature fluctuation. Experimental units of phase-change materials have been able to store and yield up to twenty-five times more heat than rock beds of equal mass under the same operating conditions [2]. A suitable phase-change material must have the following characteristics: the melting/freezing point must be at a convenient temperature, it must be nontoxic, nonflammable, noncorrosive and otherwise acceptable to building codes, it must perform reliably and without loss in efficiency over a long life cycle, and it should be inexpensive, widely available and of nonfossil fuel origin. So far, only a group of salt hydrates developed by Dr. Maria Telkes come close to meeting a number of these requirements. Sodium sulphate decahydrate (Glauber's salt) and sodium thiosulfate pentahydrate have been used in experimental solar houses. The major problems found have been supercooling, segregation of the components of the mixture after a few cycles, and failure of the containers. Certain plastics are being investigated for containers; another approach using foamed concrete block impregnated with eutectic salts and sealed with a membrane also shows promise [2].

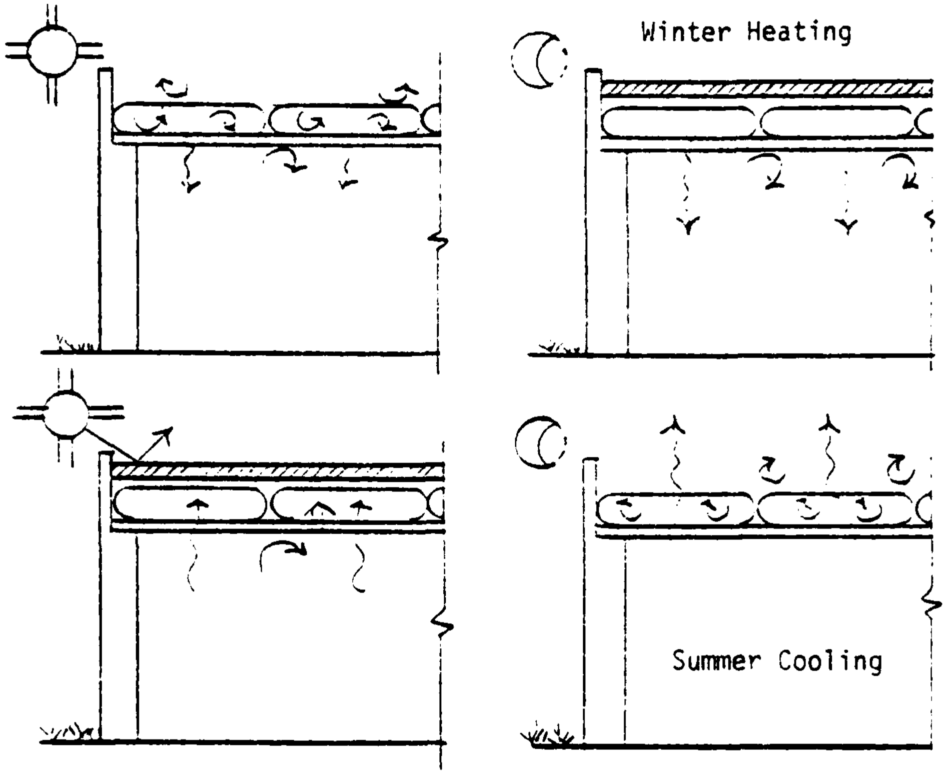


Figure 2.6 The Roof Pond in Warm Climate

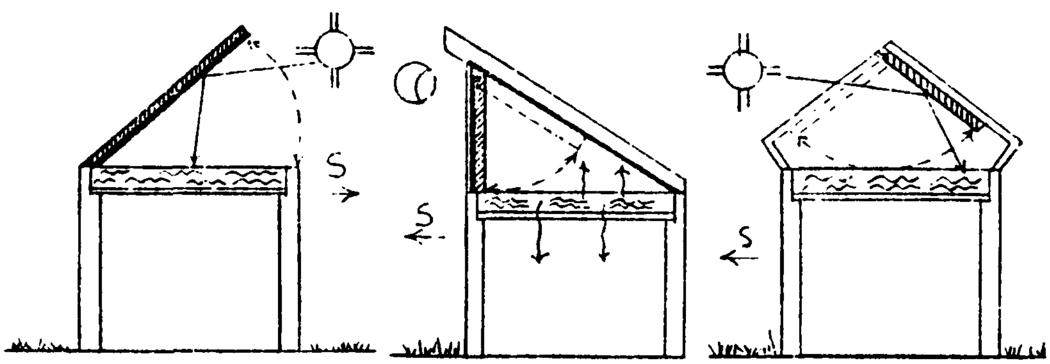


Figure 2.7 Thermal Roof Options in Colder Climates with Combined Reflector/ Night Insulation

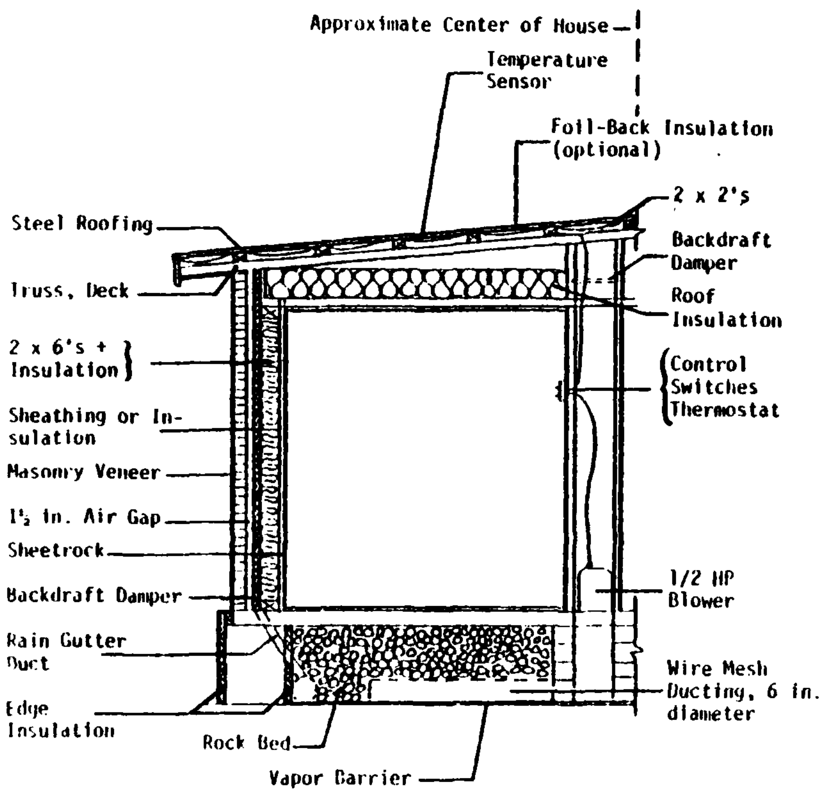
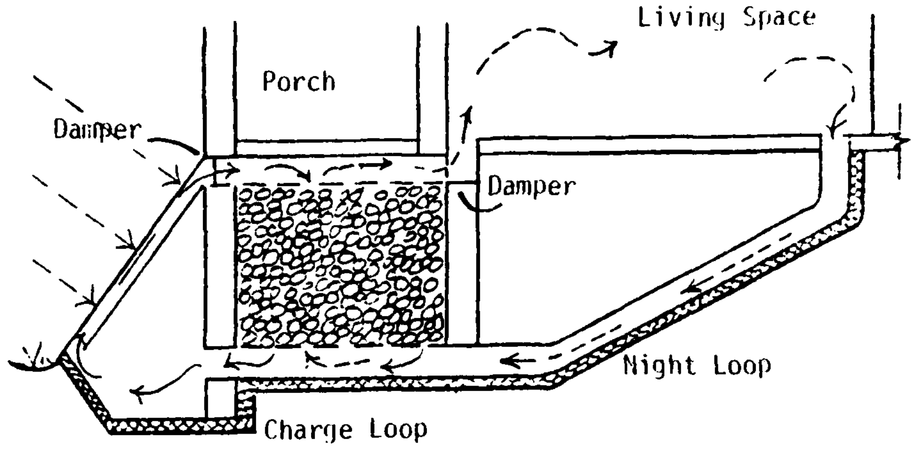
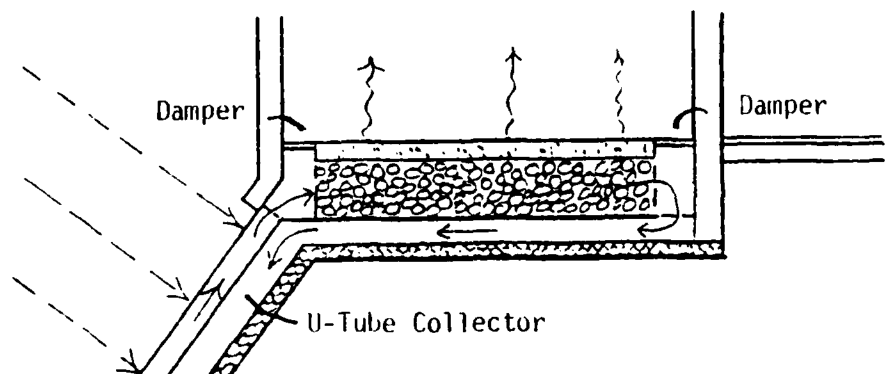


Figure 2.8 Schematic of Solar Roof System (Steel Roof, Masonry Veneer Version). The system can also be used with shingled gable roofs and stucco or siding.



(a) Double Natural Convection Loop System



(b) Natural Convective Loop System with Radiant Floor Heating from Storage at Night

Figure 2.9 Schematics of Natural Convective Loop Systems with Alternate Storage Location and Function.

3. CLIMATE AND PRELIMINARY CONSIDERATIONS

3.1 Climate

Passive solar houses must be designed specifically for the climatic conditions at the site. Besides the amount of sunshine available on any day (or the monthly average total), wind direction and velocity, precipitation and the average temperature are also important considerations. Heating degree days are the number of degrees the daily average temperature is below 65°F. A day with an average temperature of 30° has 35 heating degree days, while one with an average of 65°F or higher has none. This data is usually given in monthly and yearly totals and is used to calculate the heating load of the building, since fuel consumption for heating a building is linearly proportional to heating degree days. The data is usually available from the local Chamber of Commerce, or the values given on Table 4.8 may be used if more accurate information is not available locally. However, it must be remembered that "climate is never an average" [3], even though average monthly figures are used in the heat load calculations for convenience.

Local microclimates can also vary considerably from the official data published by the weather stations. Therefore, the data used in the calculation procedure must be adjusted as much as possible for the expected conditions at the building site; on the other hand, because of the large variations that can occur from day to day, month to month and year to year, average values can give a good overall idea of the expected performance of the design under fairly normal conditions. Also, temperature and comfort are not the same, since humidity levels and air movement as well as room surface temperatures (due to radiant heat transfer) have a large influence on human comfort and response to surrounding temperatures, as illustrated in Figure 3.1.

Besides heating degree day data, accurate solar insolation data is important in the performance calculations for passive solar houses. Here again a number of difficulties are present. Solar data is usually in the form of average daily totals of solar radiation on a horizontal surface. However, for most

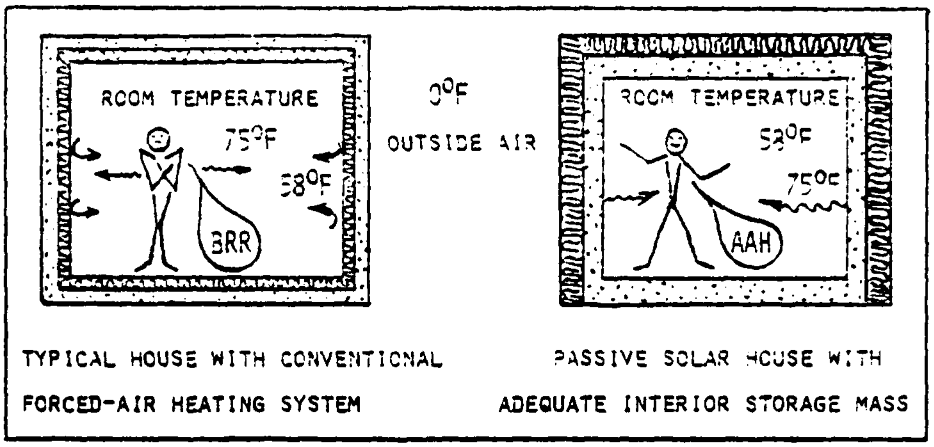


Figure 3.1 Influence of Wall Temperature on Human Comfort

passive systems, the collector (window) orientation is usually vertical or sloped, and the amount of radiation reaching the interior of the house depends on the type and number of glazings, the ground reflectance, atmospheric conditions (sky clearness, air pollution), cloud cover, and the sun's position in the sky (determined seasonally by latitude and time of day). Even less information is available on the sequence of clear and cloudy days and the percent sunshine actually received by the collector. But even where average data is available, conditions on any one day (or even monthly averages) can vary by ±30 percent or more.

Because of all these uncertainties, using averaged values in the design calculations will most likely not be a handicap in obtaining a good passive design which will perform adequately during all but very extreme years, if care is taken to get good heat distribution in the house, if climate-appropriate passive solar heat gain methods are applied (combinations of systems have an advantage here since they usually have different characteristics and peak performance during different times of the year) and especially if subsequently the house is built with top-quality construction. This last point cannot be overemphasized. The graphs and tabulated values for solar heat gain or radiation are given later in the report where the data is needed to complete the worksheets of the design procedure. In general, until more accurate information becomes available, the designer is advised to make reasonable adjustments for local conditions (i.e. increased cloudiness near mountains, air pollution near factories, reflective surfaces in front of collectors, etc.) when using the area-averaged data given in this manual. Estimates of these adjustments can be made through comparison with data from locations with similar conditions; after the designer has had some experience with passive systems design and operation, these adjustments may be made "intuitively".

3.2 Design Objectives for Temperate East Coast Climate

A well-designed and well-built passive solar building performs the following functions:

(1) It is a solar collector (by using south-facing windows, walls, and skylights, and sometimes also the roof).
(2) It is a heat storehouse (by incorporating mass inside the building).
(3) It is a heat trap (through good construction and insulation, including window night insulation).

These three have to be in a correctly-balanced relationship for the particular climatic conditions at the site. For locations with 2000-5100 heating degree days, the important design objectives are, in this order:

WARM-TEMPERATE (2000-3500 H.D.D.)	COOL-TEMPERATE (3600-5100 H.D.D.)
1. Summer Ventilation	1. Winter Sun
2. Insulation	2. Insulation
3. Winter Sun, Summer Shade	3. Summer Shade and Ventilation
4. Reduced Humidity	4. Reduced Humidity
5. Aspect Ratio*: 1.4-1.6	5. Aspect Ratio: 1.2-1.4

These objectives can be achieved by incorporating into the design these features:

(a) Direct-gain and sunspaces (without much plants in the summer)
(b) Earth berming in cooler regions, elevated plan with vented (in summer) crawl space
(c) Buffer zones on N and W, zoned plan
(d) Double-glazed windows, with triple-glazing on N in areas with over 4500 H.D.D.
(e) Functional exterior window louvers

*This means the E-W axis it longer than the N-S axis of the building, with the N-S axis assigned a base value of 1.

(f) Rain protection, drainage away from building

(g) Laundry rooms, baths and kitchens located downwind of the prevailing summer breeze

(h) Careful, open landscaping with high trees for shading without blocking summer breeze or adding summer humidity

(i) Breezeways, central ventilated halls

(j) 2-story home with minimum E-W windows (check summer ventilation)

(k) Light colors

(l) Wide eaves and wing walls only if well-ventilated

(m) High ceilings, ceiling fans, dehumidifiers

(n) Winter air lock entries convertible to screened porches in the summer

3.3 Preliminary Design Data

Before definite sketches and calculations can be made, the designer will need to assemble a variety of information on the planned building's location and use. Worksheets 1A, 1B and 1C have been provided for this purpose. The overall objective of the designer should be to produce a house that is both energy-efficient and livable (that is, it will be comfortable and meet the needs of the people living in it). Therefore, a family that is rarely home during working hours but does a lot of entertaining at night will need a different room layout than a family with preschool children who will benefit from sunny living spaces. In passive design, it is possible to build/design into the home a large degree of automatic/natural temperature control by careful placement and sizing of rooms (with proper zoning and buffer spaces), storage mass, heat-gaining and ventilating windows and shading devices, and in the selection of the most appropriate passive solar mechanisms. Such a building will be able to maintain reasonable comfort even during power failures or periods of fuel shortages.

Worksheet 1A asks for basic design information. This information defines the limits and restrictions on the building that will have to be carefully incorporated into the design. For example, if both access and best view are to the west or north, the entry will have to be provided with shelter, and the

WORKSHEET 1A

DESIGN INFORMATION

1. Location of building: ______________ Altitude: ______________
2. Building type (one or two story, split-level, etc.): ______________
3. Roof shape: ______________
4. Lot size: ______________ Special features: ______________
5. Lot orientation (in which direction will the house face the street?): ____
6. Building setbacks (check with local codes): ______________
7. Zoning restrictions and covenants: ______________
8. Lot access: ______________
9. Utility access: ______________
10. Lot slope, water runoff (erosion?), berming: ______________
11. Predominant direction of winter wind: ______ Velocity: _____ mph average
12. Predominant direction of summer breeze: _____ Velocity: _____ mph average
13. Direction of best view: ______________
14. Direction of worst view: ______________
15. Shading from neighboring houses, trees, etc.: ______________
16. Approximate floor area: ______________ Heated basement? ______________
17. Number of occupants: ______________
18. Number of bedrooms, baths: ______________
19. Other living spaces wanted: ______________
20. Life style of occupants and special needs (i.e. play area for children, space for entertaining, hobbies; space used during day, evening; special storage requirements; handicaps): ______________
21. Preferred patio location, other outdoor recreation areas: ______________
22. Occupants like the following features: ______________
23. Occupants dislike the following features: ______________

larger window size (for the view) will need to be compensated for with increased insulation. Space is also provided for listing the special needs and wishes of the people who will live in the house; it is important to consider these in the design as much as possible within the building's construction budget. People will not be happy in a solar house if annoyed daily by a poor circulation pattern, insufficient storage areas, etc., even if passive heating (and cooling) are functioning well. If the house is to be built for sale, the focus can be on a specific group in the housing market, i.e. young families, professional people or older couples, and the design is made with their special needs in mind. These special features can then be used to make the solar home attractive to this group of buyers even outside its solar features.

Worksheet 1B is used for sketching a space relationship diagram for the planned dwelling. Figure 3.2 illustrates different possibilities, depending on the requirements of the people and the lot constraints (access, size, shading, view, etc.). Even though the three designs shown in the example can be used in similar climatic zones (2000 to 3000 heating degree days), different design conditions resulted in very different space relationships.

A study of the space relationship diagram will give some indication of the passive solar mechanisms that can be employed. If living areas are to the north, a steeply sloped skylight or clerestory windows for direct gain can best be used; if no view is present, if privacy is desired or a bad view must be concealed, Trombe walls can be chosen for the south wall (or a solar greenhouse with translucent glazing). The choice depends on the people's life style -- if they have no time or inclination for gardening, the Trombe walls would be a better solution. If not much sunny south wall is available, a steeply sloping solar roof, sloped skylights or clearstory windows to the south may be the answer. If heat is not needed until early evening, unvented (to the interior) Trombe walls would serve well; for heat early in the day, direct gain should be selected instead. If there are no restrictions or preferences, it is best to begin the preliminary design with direct gain to the important living spaces only and make modifications after some preliminary calculation results have been obtained. Direct gain is the most efficient solar heat gain mechanism in cold as well as more temperate climates.

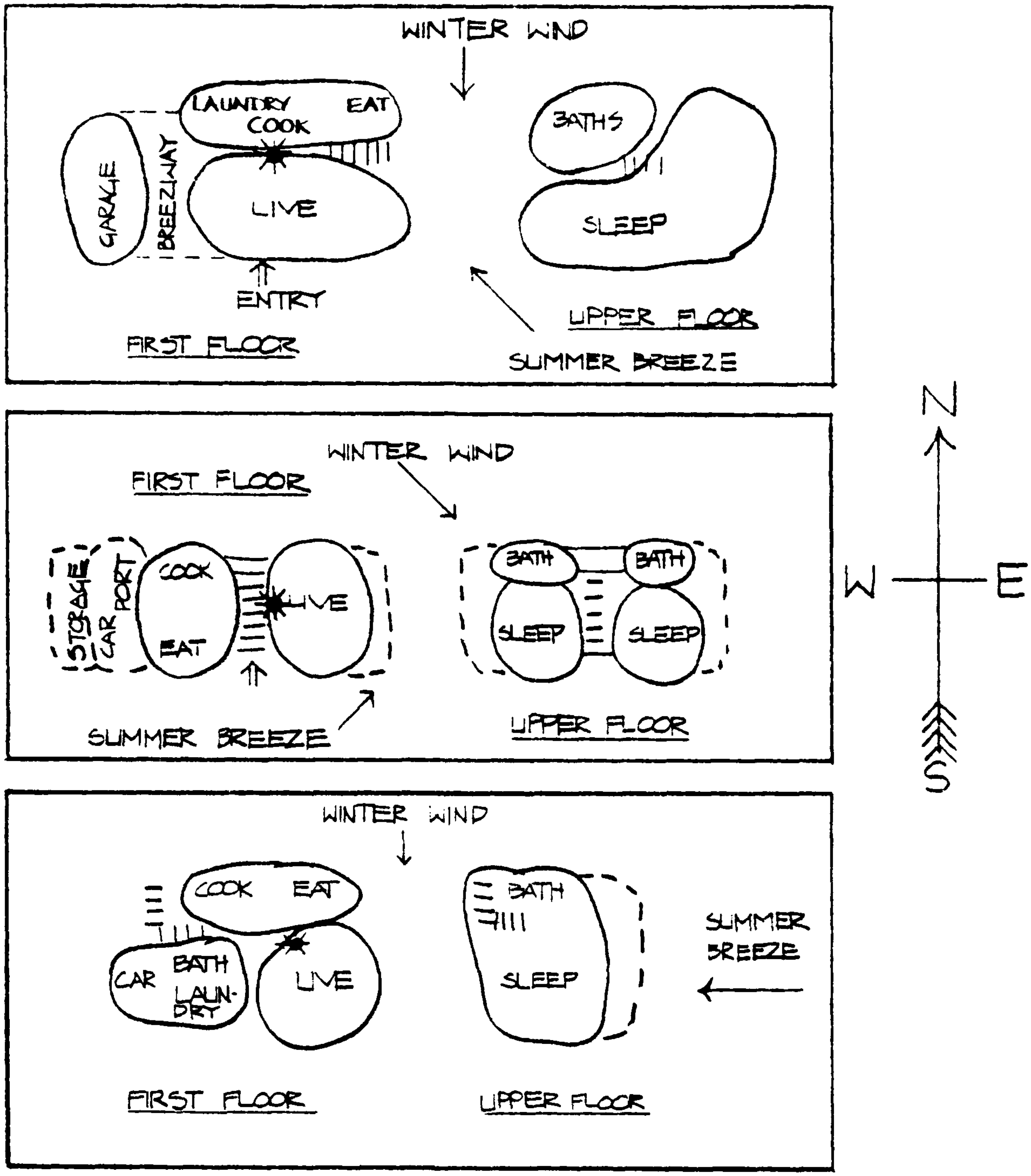


Figure 3.2 Examples of Space Relationship Diagrams

Worksheet 1C will provide additional information and a checklist for energy-conservation measures that can/should be incorporated into the design and building specifications.

WORKSHEET 1B

SPACE RELATIONSHP DIAGRAM

Floor area: ______________ sq. ft.

Sketch the location of the main entry and the living, cooking, eating and sleeping areas; then mark the major wind directions and use baths, utility, storage areas and garage as buffer zones against winter winds and summer heat. Indicate the zoning barrier (■■■) and tentatively mark the location of auxiliary heat sources (✷). Areas thus marked will need to be designed so that they can be completed closed off from the remaining sections of the house during periods when auxiliary heating is necessary. Finally, show the direction(s) of the best view (and, optionally, undersirable views which will need to be screened).

WORKSHEET 1C

ADDITIONAL INFORMATION AND CHECKLIST FOR ENERGY CONSERVATION

- [ ] Building orientation is within 5° E or W of South.
- [ ] Major axis runs east-west.
- [ ] Windbreaks are provided against winter and spring storms.
- [ ] Windows are of double or triple-glazed wood-frame (or equivalent) casement, single- or double-hung type? ____________
- [ ] Window areas to the north, east and west are minimized.
- [ ] Windows allow sufficient natural summer ventilation.
- [ ] Windows are insulated at night by (insulated drapes, shades, interior or exterior shutters): ____________
- [ ] Passive solar mechanisms included in the design are: ____________
- [ ] Storage mass is located at: ____________
- [ ] Are fans used for heat distribution: ______ Where? ______
- [ ] Is there a solar greenhouse? ____________
- [ ] Are there well-lighted spaces in the house for plants? ______
- [ ] Can sources of humidity in the house be vented easily? ______
- [ ] Is the main entry an air lock in the winter or breezeway in the summer? ____ Do other entries have air locks or storm doors? ____
- [ ] Can heated living areas be closed-off from sleeping areas? ______
- [ ] What type backup heater is planned? ____________

- [ ] Will a <u>solar water heater</u> be used? ____ What type? ______
- [ ] Solar tank location, size: ____________
- [ ] Collector location: ______ Type: ______ Area needed: ______
- [ ] Heat exchanger(s): ____________
- [ ] Collector slope (approximately equal to latitude +10° is best): ____

- [ ] Backup water heater, type, size, fuel: ____________
- [ ] Energy-efficient applicances to be used are: ____________
- [ ] Fluorescent lights are to be used in: ____________
- [ ] Fireplace has chimney on interior wall and is equipped with fresh-air duct and damper and glass screen.
- [ ] Wood burner or stove: ______ Output: ______ Btu/hr

At this point, the first sketches of the design (including the passive solar heating method(s)) should be made because dimensions are needed for the design calculations that follow. A convenient scale to use is 1" = 10'. A floor plan may be sufficient for a simple design if window sizes are listed separately; otherwise, a sketch of the elevations should be included. From this sketch, Worksheet 1D (Building Dimensions) can then be completed.

A word of caution must be added at this point; do not expect to be able to design the perfect passive solar house -- this is impossible for at least three reasons: daily and yearly variations in the weather/climate, the living habits of people, and cost-effectiveness. It is, however, not too difficult to achieve a good design if the design is kept somewhat flexible, and if compromises are made reasonably and carefully between climatic conditions, people requirements and cost. As people live in the house, it may be necessary to "fine-tune" the design during or after the first year of operation.* This should not be considered to be a flaw in the design but rather a sign of flexibility. For instance, roof overhangs in moderate and warmer climates only may be either too long for cool springs and just right for the fall, or right in the spring and insufficient during the fall. The inhabitants will be most comfortable if they are left with some control over or method of adjustment in the amount of shading or, conversely, in the amount of solar heat getting into the house. Windows with different angles (vertical or sloped) receive the maximum monthly solar radiation at different times of the year; if a combination of such windows is used (some of them operable) paired with good insulating shutters, this would allow for greater flexibility in comfort control and thus would be a desirable feature. In general, different combinations of passive solar heat gain mechanisms where warranted by the climate should be considered not only from the architectural standpoint (and cost), but also for the added measure of control possibilities that would be provided to the overall design. Another point to consider is that daily owner involvement in operating the movable window night insulation in winter and shading controls in the summer must be kept within reasonable bounds.

*In very cold climates which only have a moderate amount of direct gain solar heating, an "Operations Manual" for the people living in the house is especially recommended, since correct operation of the system is essential for comfort and energy conservation.

WORKSHEET 1D BUILDING DIMENSIONS (for Worksheet 2)		
Orientation/ Type	Gross Wall Area, ft^2 Window Door Area, ft^2 Net Wall Area, ft^2	Perimeter ft
	( ) - [( )+( )] = ( ).	( )
Total NW Total N Total NE Total E Total SE Total W Total SW Total S Total Trombe Total Air Lock		
Total	( ) - [( )+( )] = ( ).	( )
Roof	Gross Roof Area Skylights Net Roof Area ( ) - ( ) = ( )	

Thus, if the budget allows, some automatic or semi-automatic controls are preferable, such as the "Skylid" window shutter, the insulated, motorized "Thermal Gate" quilted curtain, or in very cold climates the "Bead Wall" window insulation. Climate control of course also includes the proper choice and location of backup heater(s).

A more detailed discussion of backup heating (and of other design factors, such as solar water heating, lot selection, storage alternates) is given in Reference [4].

4. CALCULATION OF BUILDING HEAT LOSS

How well will the planned building perform as a heat trap? Building heat loss occurs in two ways: by conduction through the building envelope (or skin) and by infiltration of cold air. The total building heat loss is the sum of these two losses. Reducing heat loss (or in other words, the heating load) is the first objective in passive solar design, because insulation is more cost-effective than using large amounts of glazing and storage mass.

4.1 Calculation of Building Skin Conductance

One of the primary design goals in temperate climate is prevention of winter heat loss and summer heat gain by a sufficient amount of insulation. In areas with high fuel costs and cool winters, even insulation above R-40 in the ceiling may be cost-effective [5]. Exterior wall insulation (as a rule of thumb) would be about ½ that of the roof, basement below grade insulation ½ that of the wall above grade, and basement floor insulation ½ that of below-grade basement walls.

For these calculations, two sets of input information are needed to complete Worksheet 2: the area of the exterior surfaces and their U-value. Table 4.2 lists U-Values for typical construction, or ASHRAE values and methods may be used [6]. Table 4.3 lists R-factors for a number of building and insulation materials, Table 4.4 the R-factors for air layers and air spaces.

For each surface except the floor or basement, multiply the area with its U-value. Where there are large unheated air lock spaces, such as entry or garage, consider the wall between the air lock and the heated rooms as the building's skin. But because the temperature difference between the two sides of the wall is not as large as for an exterior wall, multiply the product of its U-value and surface area by two-thirds (if the doors will be kept shut except when needed for entry or exit).

The heat loss through the floor depends on the type of foundation used.

(a) Slab-on-Grade Construction

Calculate the product of F x P, where the value of F is obtained from Table 4.1 and P is the length of the slab edge (building perimeter).

(b) Crawlspace Under Joist Floors (No Vents)

Calculate the product of Ah_c, where

$h = 0.12$ (no insulation)
$h = 0.05$ (R-11 insulation)
$h = 0.03$ (R-19 insulation)

and A is the heated gross floor area.* Figure 4.1 can be used to find interpolated values.

(c) Heated Basement

Walls down to 4 ft below grade are treated like exterior walls, where heat loss equals U x A. Heat loss for walls lower than 4 ft below grade and in contact with firm soil is determined by calculating the product h_bA. The value of h_b depends on the R-value of the insulation and can be taken from Figure 4.1. The heat loss through the floor is about half that of the below-grade walls for the same amount of insulation.

(d) Unheated Basement

Assume a similar heat loss pattern as for crawlspace. Good floor insulation is important between the heated living space and the unheated basement.

Table 4.5 gives a list of night insulation R-factors for single, double, and triple-glazed windows to achieve a given (assumed) average U-value for the window over a 24-hour day. If the window insulation will not be used for the full 14 hours (5 p.m. to 7 a.m. for example), then the R-factor of the window insulation must be increased above that given in Table 4.5.

Finally, on Worksheet 2, last column, determine the percentage contribution for the total losses of walls, windows and doors, roof, and floor.

*Gross floor area is measured from the outside of exterior wall studs (for frame walls) or exterior of masonry walls.

WORKSHEET 2

CALCULATION OF BUILDING SKIN CONDUCTANCE

Surface Type	Net Area ft^2		U-value Btu/hr-°F-ft^2		U x Area Btu/hr-°F*	% of Total
North exterior wall	____	X	____	=	____	
East exterior wall	____	X	____	=	____	
West exterior wall	____	X	____	=	____	
South exterior wall	____	X	____	=	____	
South Trombe wall	____	X	____	=	____	
Air lock walls	____	X	____	=	____	
Total Wall Heat Loss					$\boxed{}$	____
Doors: Entry	____	X	____	=	____	
Patio	____	X	____	=	____	
Other	____	X	____	=	____	
North windows	____	X	____	=	____	
East windows	____	X	____	=	____	
West windows	____	X	____	=	____	
South windows	____	X	____	=	____	
Clerestory windows	____	X	____	=	____	
Sloped skylights	____	X	____	=	____	
Horizontal skylights	____	X	____	=	____	
Total Door/Window Heat Loss					$\boxed{}$	____
Roof	____	X	____	=	$\boxed{}$	____
Floor **	____	X	____	=	$\boxed{}$	____
Total Building Skin Conductance (add boxed-in values)					____	100

* The values here may be rounded off to whole numbers, as extreme accuracy is not needed.

** Crawlspace = Ah_c (see Figure 4.1)

Slab = F x P (see Table 4.1)

Heated basement = $UA_{\text{wall above grade}} + h_b A_{\text{wall below grade}} + h_c A_{\text{floor}}$

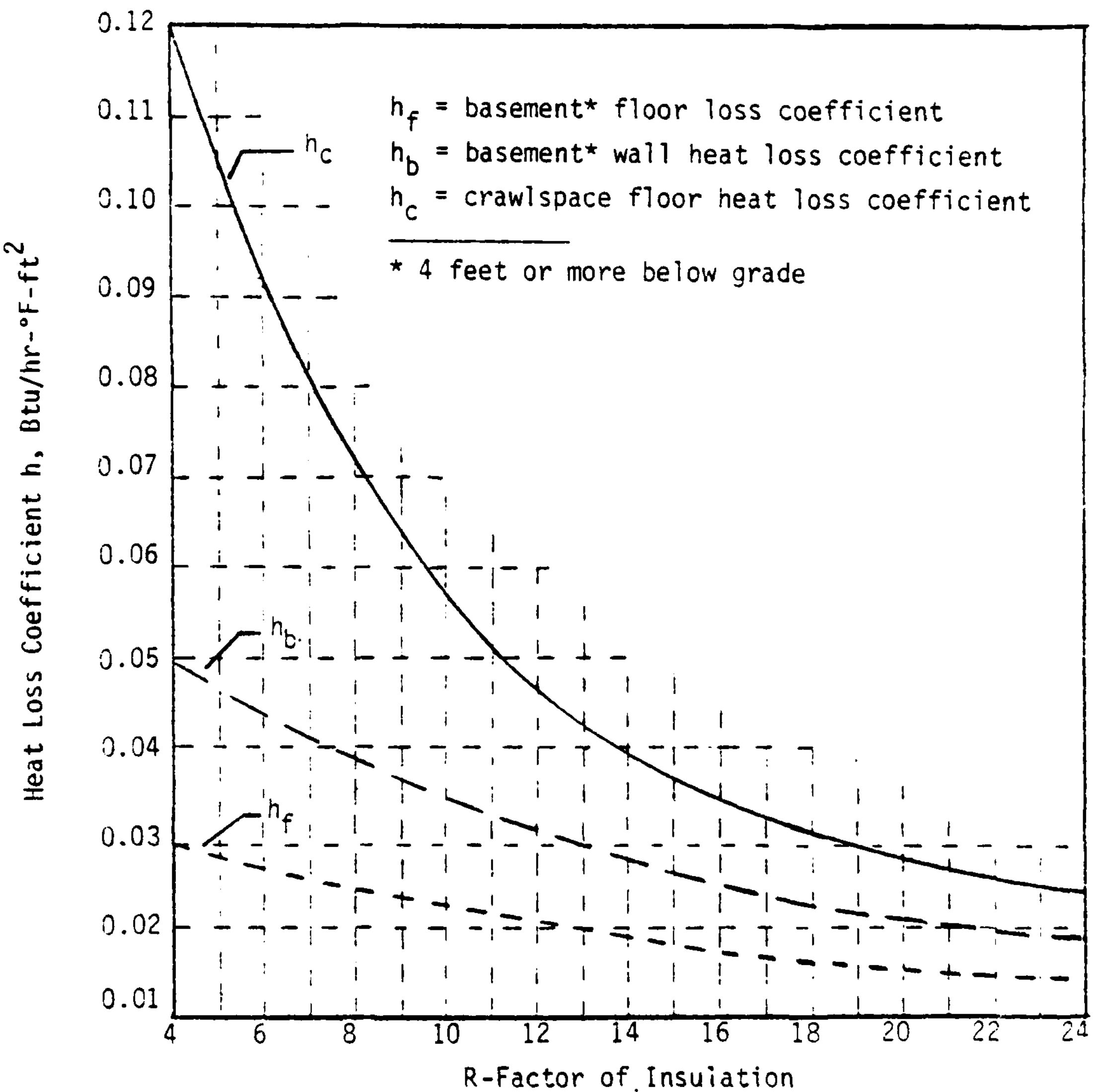
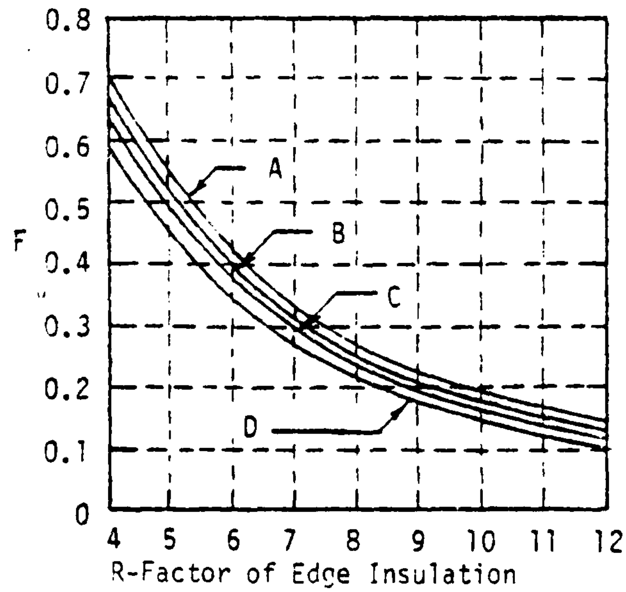


Figure 4.1 Heat Loss Coefficients for Basement and Crawlspace Heat Loss Calculations.

TABLE 4.1

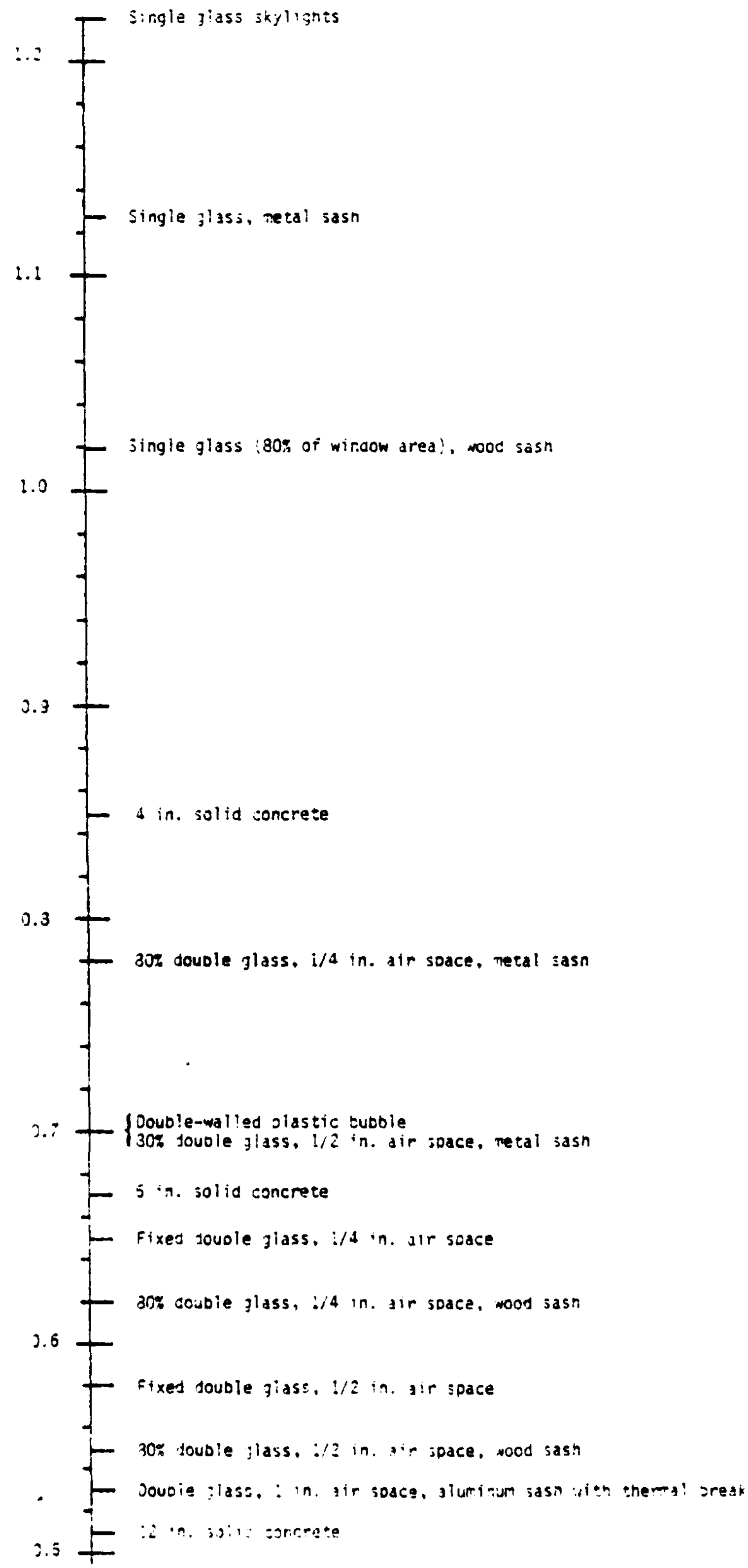
Heat Loss Factors for Concrete Floor Slabs at Grade Level per Foot of Slab Edge

Degree-Days, Zone	Depth of Insulation	F, Btu/hr-°F per ft Perimeter					
		R-12	R-10	R-8	R-6	R-5	R-2.5
A, 2500	4-6 in.	0.14	0.19	0.26	0.41	0.55	1.04
B, 3500	12 in.	0.13	0.18	0.25	0.39	0.52	1.00
C, 4500	18 in.	0.12	0.17	0.24	0.37	0.49	0.96
D 5500, 6500, 7500	24 in.	0.10	0.15	0.22	0.34	0.45	0.90



EXAMPLE: The slab heat loss for a home with a 140 ft perimeter in Zone D would be, using 3 inches of rigid polystyrene with an R-value of 3.85 per inch: (3 inches) x (3.85) = R - 11.5 which would give an F-value of about 0.11; thus the heat loss is 140(0.11) = 15 Btu/hr-°F. Instead, 24 in. wide and 2 in. thick polyurethane with an R-value of 5.88 per inch could have been used to get about the same heat loss. The values in Table 4.1 can be interpolated for the R-factor of the insulating material used.

TABLE 4.2
U-Values for Typical Building Construction
(for Passive Solar Houses), Btu/hr-ft^2-F°



(Continued)

TABLE 2 (Continued)

0.5	
	1-1/2 in. solid wood door
	1-3/4 in. steel door with solid polystyrene core
	30% triple glass, metal sash
	8 in. common brick
0.4	
	Triple glass, fixed
	80% triple glass, wood sash
	1-1/2 in. solid wood door with metal storm door
	12 in. common brick
0.3	
	1-1/2 in. solid wood door with 50% glass/wood storm door
	10 in. adobe, 3/4 in. stucco wall (light color)
	10 in. adobe, 3/4 in stucco wall (medium color) Double-glazed uninsulated Trombe wall
0.2	
	Double-glazed water wall with night insulation
0.15	Double glaze with well-setting thermal shutters (depending on R-value and installation)
	20 in. adobe, 3/4 in. stucco wall
	Double glazed Trombe wall with night insulation
0.10	
	Stucco wall, 2 x 4's with R-11 insulation, 1/2 in. gypsum board
	Wood siding, 2 x 4's with R-11 insulation, 1/2 in. gypsum board
	24 in. adobe, 3/4 in. stucco wall, 1 in. foam (R-9) on exterior 4 in. common brick veneer, R-15 insulation, 1/2 in. gypsum board
	Wood siding, 2 x 6's with R-18 insulation, 1/2 in gypsum board
0.05	10 in. adobe, 3/4 in. stucco wall, foam (R-18) on exterior
	Wood siding or brick, R-4 board, 2 x 6's with R-19 insulation. Roof with R-19 insulation
0.04	
	Double wall of 2 x 4's (offset, 24 in. O.C.) with air gap, R-22 insulation
	24 in. adobe, 3/4 in. stucco wall, 2 in. foam (R-20) on exterior
0.03	
	Roof with R-38 insulation (depends on deck layers, reflective surfaces, additional air spaces)
0.02	R-40 walls R-80 roof
0.01	
0	

TABLE 4.3 R-FACTORS OF BUILDING MATERIALS (from Ref. [6])

Material and Description		Density (lb/ft^3)	R-Value per inch thickness	R-Value for listed thickness
Building Boards, Panels, Flooring				
Asbestos cement board		120	0.25	--
Asbestos-cement board	1/8"	120	--	0.03
Gypsum or plaster board	3/8"	50	--	0.32
Gypsum or plaster board	1/2"	50	--	0.45
Plywood (see Siding Materials)		34	1.25	--
Sheathing, wood fiber (impregnated or coated)	25/32"	20	--	2.06
Wood fiber board (laminated or homogenous)		26	2.38	--
Wood fiber, hardboard type		65	0.72	--
Wood fiber, hardboard type	1/4"	65	--	0.18
Wood subfloor	25/32"	--	--	0.98
Wood, hardwood finish	3/4"	--	--	0.68
Building Paper				
Vapor-permeable felt		--	--	0.06
Vapor-seal, 2 layers of mopped 15 lb felt		--	--	0.12
Vapor-seal plastic film		--	--	negl.
Finish Materials				
Carpet and fibrous pad		--	--	2.08
Carpet and rubber pad		--	--	1.23
Cork tile	1/8"	--	--	0.28
Terrazzo	1"	--	--	0.08
Tile (asphalt, linoleum, vinyl, rubber)		--	--	0.05
Gypsumboard	1/2"	--	--	0.45
Gypsumboard	5/8"	--	--	0.56
Hardwood flooring	25/32"	--	--	0.68
Insulating Materials				
Blankets and Batts:				
Mineral wool, fibrous form (from rock, slag or glass)		0.5	3.12	--
		1.5-4.0	3.70	--
Wood fiber		3.2-3.6	4.00	--
Boards and Slabs:				
Cellular glass	30°F	9	2.70	--
Corkboard	30°F	6.5-8.0	3.85	--
	30°F	12	3.45	--
Glass fiber	90°F	4.0-9.0	3.85	--
	30°F		4.55	--
Expanded rubber (rigid)	75°F	4.5	4.55	--
Expanded polyurethane (R-11 blown; 1" thickness or more)	100°F	1.5-2.5	5.56	--
	25°F		5.88	--
Expanded polystyrene, extruded	75°F	1.9	3.85	--
	30°F		4.17	--

Material and Description		Density (lb/ft^3)	R Value per inch thickness	R Value for listed thickness
Expanded polystyrene molded beads	75°F	1.0	3.57	-
	30°F		3.85	
Mineral fiberboard, felted core or roof insulation		16-17	2.94	
acoustical tile (ave.)		21	2.73	-
Mineral fiberboard, molded acoustical tile[1]		23	2.38	-
Wood or cane fiberboard acoustical tile	1/2"	--	--	1.19
interior finish		15	2.86	--
Insulating roof deck	1"	--	--	2.78
	2"	--	-	5.56
	3"	--	--	8.33
Shredded wood (cemented, preformed slabs)		22	1.67	--
Loose Fills:				
Macerated paper or pulp		2.5-3.5	3.57	-
Mineral wool	90°F	2.0-5.0	3.33	--
	30°F		4.10	--
Perlite (expanded	90°F	5.0-8.0	2.63	--
	30°F		2.74	--
Vermiculite (expanded)	90°F	7.0-8.2	2.08	--
	30°F		2.27	--
Sawdust or shavings		0.8-15	2.22	--
Masonry Materials, Concretes				
Cement mortar		116	0.20	--
Gypsum-fiber concrete (87½% gypsum, 12½% concrete)		51	0.60	--
Lighweight aggregates (expanded shale, clay or slate; expanded slags, or cinders; pumice; perlite or vermiculite; cellular concretes)		120	0.19	--
		100	0.28	--
		80	0.40	--
		60	0.59	--
		40	0.86	--
		20	1.41	-
Sand and gravel or stone aggregate (oven dried)		140	0.11	--
Sand and gravel or stone aggregate (not dried)		140	0.08	--
Stucco		116	0.20	-
Masonry Units				
Brick, common[1] } typical value		120	0.20	--
Brick, face[1] } typical value		130	0.11	--
Clay tile, hollow				
1 cell deep	3"	--	--	0.80
1 cell deep	4"	--	-	1.11
2 cells deep	6"	--	--	1.52
2 cells deep	8"	--	--	1.65
3 cells deep	10"	--	--	2.22
3 cells deep	12"	--	--	2.50

Continued

Table 4.3 Continued

Material and Description		Density (lb/ft³)	R-Value per inch thickness	R-Value for listed thickness
Concrete block, 3 oval core				
Sand and gravel aggregate	4"	--	--	0.71
	8"	--	--	1.11
	12"	--	--	1.28
Cinder aggregate	3"	--	--	0.86
	4"	--	--	1.11
	8"	--	--	1.72
	12"	--	--	1.89
Lightweight aggregate	3"	--	--	1.27
(expanded shale, clay or slate	4"	--	--	1.50
or slag; pumice)	8"	--	--	2.00
	12"	--	--	2.72
Concrete blocks, rectangular core				
Sand and gravel aggregate				
2 core, 36 lb*	8"	--	--	1.04
same, filled cores**		--	--	1.93
Lightweight aggregates				
3 core, 19 lb*	6"	--	--	1.65
same, filled cores**		--	--	2.99
2 core, 24 lb*	8"	--	--	2.18
same, filled cores**		--	--	5.03
3 core, 38 lb*	12"	--	--	2.48
same, filled cores**		--	--	5.82
Stone, lime or sand		--	0.08	--
Granite, marble		150-175	0.05	--
Adobe	10"	--	--	2.78
	14"	--	--	3.89
Plastering Materials				
Cement plaster, sand aggregate		116	0.20	--
Gypsum plaster				
Lightweight aggregate	1/2"	45	--	0.32
Lightweight aggregate	3/8"	45	--	0.39
Same, on metal lath	3/4"	--	--	0.47
Perlite aggregate		45	0.67	--
Sand aggregate		105	0.18	--
Same, on metal lath	3/4"	--	--	0.10
Same, on wood lath	3/4"	--	--	0.40
Vermiculite aggregate		45	0.59	--
Roofing Materials				
Asbestos-cement shingles		120	--	0.21
Asphalt roll roofing		70	--	0.15
Built-up roofing	3/8"	70	--	0.44
Slate roofing	1/2"	--	--	0.05
Wood shingles		-	--	0.94
Built-up roofing		-	--	0.33

Material and Description		Density (lb/ft³)	R-Value per inch thickness	R-Value for listed thickness
Siding Materials				
Shingles				
Asbestos-cement		120	--	0.21
Wood, 16" with 7 1/2" exposure		--	--	0.80
Wood, double 16" with 12" exposure		--	--	1.19
Wood, plus insulating backer board	5/16"	--	--	1.40
Siding				
Asbestos-cement lapped	1/4"	--	-	0.21
Asphalt roll siding		--	--	0.15
Asphalt insulating siding	1/2"	--	--	1.46
Wood, drop (1" x 8")		--	--	0.79
Wood, drop (1/2" x 8" lapped)		--	-	0.81
Wood, bevel (3/4" x 10" lapped)		--	--	1.05
Plywood, lapped	3/8"	--	--	0.59
Plywood	1/4"	--	--	0.31
	3/8"	--	--	0.47
	1/2"	--	--	0.62
	5/8"	--	--	0.78
	3/4"	--	--	0.94
Stucco		116	0.20	--
Sheathing, insulating board	1/2"	--	--	1.32
(regular density)	25/32"	--	--	2.04
Woods				
Hardwoods (maple, oak)		45	0.91	-
Softwoods (fir, pine)		32	1.25	-
	25/32"	32	--	0.98
	1-5/8"	32	--	2.03
	2-5/8"	32	--	3.28
	3-5/8"	32	-	4.55
Particleboard				
Low density 37#/ft³	1"	--	-	1.85
Medium density 50#/ft³	1"	--	--	1.06
High density 62.5#/ft³	1"	--	--	0.85
Wood Doors				
Solid core	1"	--	--	1.56
	1-1/4"	--	--	1.82
	1-1/2"	--	--	2.04
	2"	--	--	2.33

*Weights of blocks approximately 7-5/8" high by 15-3/8" long.

**Vermiculite, perlite, or mineral wool insulation.

TABLE 4-4

R-VALUES OF AIR FILMS AND AIR SPACES
(from Ref. [6])

Type and Orientation of Air Film	Direction of Heat Flow	R-value for Air Film On: Non-reflective surface	Fairly reflective surface	Highly reflective surface
Still air:				
Horizontal	up	0.61	1.10	1.32
Horizontal	down	0.92	2.70	4.55
45° slope	up	0.62	1.14	1.37
45° slope	down	0.76	1.67	2.22
Vertical	across	0.68	1.35	1.70
Moving Air:				
15 mph wind	any*	0.17	—	—
7½ mph wind	any†	0.25	—	—

Orientation & Thickness of Air Space	Direction of Heat Flow	R-value for Air Space Facing:‡ Non-reflective surface	Fairly reflective surface	Highly reflective surface
Horizontal 1/4"	up*	0.87	1.71	2.23
4"		0.94	1.99	2.73
3/4"	up†	0.76	1.63	2.26
4"		0.80	1.87	2.75
3/4"	down*	1.02	2.39	3.55
1-1/2"		1.14	3.21	5.74
4"		1.23	4.02	8.94
3/4"	down†	0.84	2.08	3.25
1-1/2"		0.93	2.76	5.24
4"		0.99	3.38	8.03
45° slope 3/4"	up*	0.94	2.02	2.78
4"		0.96	2.13	3.00
3/4"	up†	0.81	1.90	2.81
4"		0.82	1.98	3.00
3/4"	down*	1.02	2.40	3.57
4"		1.08	2.75	4.41
3/4"	down†	0.84	2.09	3.34
4"		0.90	2.50	4.36
Vertical 3/4"	across*	1.01	2.36	3.48
4"		1.01	2.34	3.45
3/4"	across†	0.84	2.10	3.28
4"		0.91	2.16	3.44

‡One side of the air space is a non-reflective surface.
*Winter conditions.
†Summer conditions.

TABLE 4.5

Average Window U-Values (24 Hours) and
Corresponding R-Factor of Night Insulation (14 Hours)
for Single, Double and Triple Glazing

24-Hour Average U-Value Used in Heat Loss Calculations	R-Factor of Night Insulation Used 14 Hours (incl. Air Space)		
	Single Glazing	Double Glazing	Triple Glazing
0.56	1.4		
0.52	1.6		
0.50	1.7		
0.46	2.0	0.4	
0.45	2.1	0.5	
0.44	2.2	0.6	
0.43	2.3	0.7	
0.42	2.4	0.8	
0.41	2.5	0.9	
0.40	2.6	1.0	
0.395	2.65	1.05	
0.39	2.7	1.1	
0.38	2.85	1.2	
0.37	3.0	1.35	
0.36	3.1	1.5	
0.35	3.2	1.6	
0.34	3.35	1.75	
0.33	3.5	1.9	
0.30	4.0	2.15	
0.29	4.25	2.4	1.0
0.28	4.5	2.8	
0.27	4.75	3.0	
0.26	5.0	3.25	
0.25	5.2	3.5	2.0
0.24	5.4	3.75	
0.23	5.7	4.0	
0.22	6.0	4.5	3.0
0.21	6.4	5.0	
0.20	6.9	5.5	
0.19			4.0
0.17			5.0
0.16			6.0
0.15		8.2	
0.14			7.0
0.13			8.0

TABLE 4.6

Recommended Ranges for Surface Heat Losses in Direct Gain Passive Solar Houses (in Percent)

Surface	One-Story House	Two-Story House
Exterior Walls	20-25%	25-30%
Windows and Doors	45-50%	50-55%
Roof	10-15%	5-10%
Slab/Floor	15-20%	10-15%

If the distribution of the building skin conductance for a direct-gain building falls quite a bit outside the percentage ranges indicated in Table 4.6, the design and building specifications should be reconsidered. Can window and door openings on the east, north and west sides of the house be reduced without reducing summer ventilation or natural lighting and still comply with local building code requirements? Can the building shape be made more compact (the less wall area, the less heat is lost)? Can wall, roof, slab edge insulation be increased? Can window glass, shutter or curtain U-value be improved?

If the design includes a Trombe wall or greenhouse, the calculated values will not fit exactly into the ranges given in Table 4.6; wall losses for the walls will be higher and for windows lower for Trombe wall designs, with the opposite being true for exposed greenhouse applications. Heat loss calculations following the method here take the loss of the Trombe wall into account in finding the building skin conductance and thermal load; some other methods, such as those developed by Balcomb [7] do not. In retrofit projects, it may not be possible to bring the building's heat losses within the recommended range without a very great expenditure of money, time and trouble. For apartment houses, heat loss depends on the location of each unit, with the ground floor apartments at each end having generally the highest losses, followed by the end apartments on the top floor; interior units have the smallest losses. Heating requirements among these units can be equalized somewhat by choosing much better window night insulation for the more exposed apartments.

4.2 Calculation of Infiltration Load and Modified Building Heat Loss Coefficient C_B

Worksheet 3 is used to calculate the infiltration load and the modified building heat loss coefficient. Volume is the gross floor area of the heated space times the average ceiling height. The heat capacity of air depends on altitude and is

C_p (sea level) = 0.018 Btu/ft^3-°F
C_p (1000 ft) = 0.0175 Btu/ft^3-°F
C_p (2000 ft) = 0.0165 Btu/ft^3-°F
C_p (3000 ft) = 0.016 Btu/ft^3-°F
C_p (4000 ft) = 0 155 Btu/ft^3-°F
C_p (5000 ft) = 0.015 Btu/ft^3-°F
C_p (6000 ft) = 0.0145 Btu/ft^3-°F
C_p (7000 ft) = 0.014 Btu/ft^3-°F
C_p (8000 ft) = 0.0135 Btu/ft^3-°F
C_p (9000 ft) = 0.013 Btu/ft^3-°F

The infiltration load is the heat needed to warm the cold air seeping into the building through even the tiniest cracks, such as around windows, doors, and where two different building materials meet, as for example between slab and framing.

The air change per hour (ACH) is a very important parameter; unfortunately, it can only be roughly estimated. A well-built solar house with very tight windows, caulking, weatherstripping, storm doors, air lock spaces, enclosed fireplace, few vents, some berming and landscaping with wind breaks, etc., can be assumed to have from 0.3 to 0.6 ACH, depending on the amount of insulation and quality of construction. If construction cannot be closely supervised, if the house is located in a very exposed area, and if air locks have been omitted because of cost-cutting, then it is safer to assume a minimum of 3/4 ACH or more. A well-built conventional house is assumed to have an ACH = 1. An older home with sliding windows could have an ACH of 1-1/2 or more. To reduce infiltration, careful attention must be paid to areas where cold air can enter, i.e. electrical outlets and piping in exterior walls, and skylights and vents through the roof. Fireplaces should be equipped with glass screens and a fresh-air duct with damper, or air-tight stoves should be used instead.

WORKSHEET 3

CALCULATION OF INFILTRATION LOAD AND
MODIFIED BUILDING HEAT LOSS COEFFICIENT C_B

House Volume = Gross Floor Area x Ceiling Height =(   )(   )=____

Infiltration Load = Volume x C_p x ACH   ACH = Air Change/Hour

= (   ) x (   ) x (   )

= ________ Btu/hr-°F

Modified Building Heat Loss Coefficient, C_B

= [Building Skin Conductance* + Infiltration Load]

= 24 [(   ) + (   )] = 24 (   )

= ______________________ Btu/D.D.

Gross Heated Floor Area of Building = _________ ft^2

C_B/A = (   ) / (   )

= _____________ Btu/ft^2-D.D.   D.D. = Degree Days**

* From Worksheet 2.

**"Degree Days" is an indication of the "coldness" of the climate for heating calculations; the degree-day value for a particular day is the difference between the average daily outdoor temperature and 65°F; the data is usually given in monthly and yearly totals.

TABLE 4.7

Recommended Design Heat Loss Range for Passive Solar Houses

Heating Degree Day Range	C_B/A (Btu/ft^2-D.D.)
2000 - 4000	4.5 - 6.5
4000 - 6000	3.5 - 5.5
6000 - 8000	2.5 - 4.5
Above 8000	1.5 - 3

Table 4.7 is given as a checkpoint of the thermal performance of the design, to show how well the house will perform as a thermal storehouse. It has been compiled from published data on a number of passive direct gain solar houses that use only wood stoves as backup heaters. The calculated C_B/A should fall within the indicated range for passive solar homes that expect to gain over 80 percent of their heat load by solar. Values toward the lower limit within a given range of Table 4.7 should be achieved by larger houses and for locations towards the upper degree day limit within the zone. Houses with extensive uninsulated Trombe walls will have values somewhat exceeding these numbers. Note that houses with construction and insulation yielding these values will exceed FHA and TEA (1975) standards [8] by a factor of at least 2. The proposed BEPS standards, for some regions in the U.S., are even less strict than present FHA standards; as written, they do not encourage the use of passive solar. It is of course possible to do even better than these guidelines (Table 4.7); the building in this case would be extremely well-built and insulated for the particular winter climate; one should, however, investigate the cost-effectiveness and the building's summer performance (i.e. are enough openings left for efficient natural ventilation?). If the calculated C_B/A is higher than the indicated range, the building specifications (U-values, dimensions/shape) should be reviewed in terms of the design objectives. If no changes are desired at this point, the designer should proceed with the calculations; later the choice can be made to either increase solar collection if possible or decrease heat loss depending on which is more practical and economical. For massive adobe construction, the "effective U-values" as developed by the University of New Mexico [9] may be used in these calculations for the walls only, not for the windows. Retro-fits may have difficulty achieving such small heat loss factors without a large

investment in added insulation. The cost-effectiveness of each case should be evaluated individually. The solution will most likely be a compromise between a somewhat higher heat loss at lower cost. Also, retrofits are usually equipped with a full-size backup, thus a larger heat loss is not as critical here as for a new passive design with just a small backup.

For the purposes of this design procedure (under this Navy contract), Table 4.8 lists heating degree days for some representative locations. More accurate local information may be available from local Chambers of Commerce. Yearly and even monthly totals can vary tremendously from one year to the next, thus using area-averaged values should be adequate to get an overall indication of the performance of the design during all but very extreme conditions. Reference [13] also lists heating degree data for many U.S. locations.

TABLE 4.8
Heating Degree Days for Navy Locations
With Temperate East Coast Climate
(Source: Ref. [10])

Location	Total	J	A	S	O	N	D	J	F	M	A	M	J
Philadelphia, Pennsylvania													
H.D.D. =	5100	-	-	50	290	620	970	1020	890	750	390	120	-
Baltimore, Maryland													
H.D.D. =	4700	-	-	50	270	590	910	940	820	680	340	100	-
Washington, D.C.													
H.D.D. =	4300	-	-	50	230	530	840	880	770	630	290	80	-
Norfolk, Virginia													
H.D.D. =	3400	-	-	-	140	410	700	740	660	530	220	-	-
Wilmington, North Carolina													
H.D.D. =	2400	-	-	-	100	300	520	550	470	360	100	-	-
Charleston, South Carolina													
H.D.D =	2000	-	-	-	50	280	470	480	390	290	40	-	-

4.3 Calculation of Building Net Heating Load Profile

In this step, the modified building heat loss coefficient C_B (from Worksheet 3) is used with the heating degree day information in Table 4.8 to find the thermal load of the building. In Worksheet 4, the estimated internal heat source contribution must also be listed in order to obtain the net thermal load; approximate values are given in Table 4.9. In conventional houses, the heat from the internal sources is used to raise the temperature from the 65° base (used in the number of heating degree days) to a more comfortable 68 to 70°F and is thus not separately taken into account. In well-insulated passive solar homes internal heat sources are important in reducing the thermal load and must thus be taken into account. Many passive homes with sufficient storage are quite comfortable at 65°F. The monthly heating degree days are multiplied with the value of C_B to get the gross thermal load in million Btu/month (or MBtu/month). The internal heat contribution by people, lights and appliances is then subtracted to get the net thermal load of the building, that is the heat needed to be supplied by other sources such as solar and the backup heater.

Table 4.9

Contribution of Internal Heat Sources

300,000 Btu/month per adult per 24-hour occupancy
1,000,000 Btu/month for kitchen appliances and lights (2000 ft^2 house)
200,000 Btu/month for washer/dryer if located in heated area
100,000 Btu/month for water heater if located in heated area

The figures for internal heat contribution are rough estimates; they can be calculated more accurately using ASHRAE methods [6]; however, since other assumptions such as infiltration are not that accurate (and depend on the occupants' living pattern), extreme accuracy is not needed. If an outdoor clothesline will be used frequently in the winter, this will reduce heat gain by 100,000 Btu/month. For a very small house (or a small family) the figures for lights, applicances and water heater should be reduced; also use smaller values if the family is a very energy-conscious and careful user of energy. In estimating the internal heat contribution, caution is advised when there is any doubt about the future energy consumption pattern of the occupants.

WORKSHEET 4

CALCULATION OF BUILDING THERMAL LOAD PROFILE

Modified Building Heat Loss Coefficient C_B from Worksheet 3 = _____ Btu/D.D.

Month	Degree Days per Month	$\times C_B$	=	Gross Thermal Load, MBtu/month	−	Internal Heat Sources, MBtu/month	=	Net Thermal Load, MBtu/month
Aug.	_____	$\times C_B$	=	______	−	______	=	________
Sept.	_____	$\times C_B$	=	______	−	______	=	________
Oct.								
Nov.								
Dec.								
Jan.								
Feb.								
Mar.								
Apr.								
May								
Jun.								
Jul.								

MBtu = Million Btu

5. CALCULATION OF SOLAR HEAT GAIN AND AUXILIARY LOAD

How well will the designed building perform as a solar collector? To calculate the solar heating contribution, data on average monthly solar heat gain through south-facing glazing or solar radiation on the collector surface is needed. These are provided in Figures 5.2 to 5.4. Data for these figures have been assembled from a number of sources, i.e. References [10, 11, 12]. A judgment has to be made by the designer on the basis of local conditions in adjusting the average values more accurately up or down. Worksheet 5 must be completed for each solar heating mechanism present in the design.

5.1 Effectiveness Factor and Solar Data

To complete Worksheet 5, the net effective collector area must be determined. This is a combination of frame shading, type and number of glazings and the solar heat gain mechanism efficiency and can be calculated by using the factors listed in Table 5.1. The gross collector area (usually taken from the overall dimensions of the window) is multiplied by a frame shading factor (0.95 for the narrow sashes of fixed windows, 0.8 or less for wider wood sashes and windows with many small panes). It is assumed that window screens are removed and glazing is cleaned in the winter to allow maximum heat gain. The window (or collector) area is then additionally multiplied by the "effectiveness" factor, depending on the glazing and collecting method used, and the resulting number is listed on the top of Worksheet 5. The purpose of the "effectiveness" factor is to provide an adjustment for the efficiencies and operational characteristics of the various passive solar heat gain mechanisms, so that a single solar estimator curve can be used for the combined heat gain. The values for Trombe walls have been checked against Balcomb's work [7], those for direct gain and solar roofs against actual operating experience. The value for sunspace (a feature of more complex designs) and for roof ponds are estimates and need verification. At present, these factors can be used with a good degree of reliability in climates which have over 60 percent or more monthly possible sunshine (Figure 5.1). For climates that have considerably more cloudy days in winter, and are thus designed with less storage capability, it is recommended that the effectiveness factor be

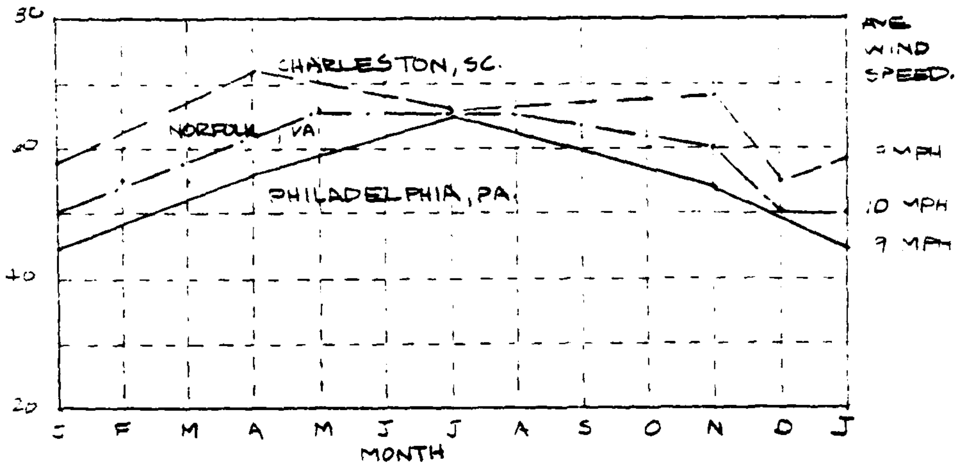


Figure 5.1 Mean Percent Sunshine Possible Along U.S. East Coast (Temperate Climate), from Ref. [13].

multiplied by an additional 0.90 to account for the reduced efficiency of the storage. However, using excessive amounts of storage is not advisable, because this would then reduce the efficiency of the auxiliary heating system and would add to summer discomfort in warm, humid climates. Additional studies will need to be made to obtain more accurate estimates of performance.

If the design incorporates an exposed greenhouse, a series of separate calculations for the greenhouse alone should be made, using Worksheets 1 through 5. The monthly heat loss of the greenhouse is subtracted from the monthly solar heat absorbed and multiplied by a factor of 0.8 if the heat distribution is easily made with large openings (windows, vents with fans, etc.). If the heat distribution is more indirect, (i.e. storage wall only) the heat gain must be reduced by a factor of 0.5 for each month. (These factors are only estimates and will need to be checked against operational data; however, they do represent a reasonable adjustment for the reduced efficiency; the resulting overall auxiliary load figures should be within the accuracy of the other input data and operating conditions, considering the large possible yearly and daily variation in the weather.) Worksheet 5A can be used to compute the adjusted net solar greenhouse heat gain.

The effect of a roof overhang can be calculated with the tables given in the following section. If the home will have an off-south (skew) orientation, solar heat gain will also be reduced, as indicated in Section 5.3. In cold climates, it is strongly recommended to face the building as nearly true south as possible. In temperate climates, southwest and west-facing walls and windows will require careful summer shading with deciduous trees or vines, vertical grilles, etc.

TABLE 5.1
Effectiveness Factors

(to adjust heat gain from different solar mechanism to the application of a single estimator curve)

Multiply the gross window collector area by a frame shading factor of 0.80 to 0.95 depending on construction (for solar roofs and roof ponds, use the unshaded (projected) horizontal roof area instead) <u>and</u> by one of the following:

0.85	for double-glazed direct-gain windows with regular glass
0.90	for double-glazed direct-gain windows with low-iron glass
1.00	for single-glazed direct-gain windows with regular glass
1.05	for single-glazed direct-gain windows with low-iron glass
0.70	for double-glazed vented uninsulated Trombe walls*
0.65	for double-glazed unvented uninsulated Trombe walls
0.80	for double-glazed vented Trombe walls with R-9 night insulation*
0.75	for double-glazed unvented Trombe walls with R-9 night insulation
1.05	for double-glazed water walls with R-9 night insulation*
1.10	for single-glazed water walls with R-9 night insulation*
0.50	for well-insulated roof ponds
0.075	for dark-colored shingle or metal solar roofs
0.04	for medium-colored built-up solar roofs

*With optimum wall thickness of 10 to 16 inches and thermal storage of about 0.45 Btu/°F-ft^2 [7]

WORKSHEET 5

CALCULATION OF SOLAR HEATING CONTRIBUTION

Mechanism: ______________________________

Net Effective Collector Area: ____________ $ft^2 = A_{eff}$

$A_{eff} = A_{gross}$ x (Frame Shading) x (Effectiveness, Table 5.1)

Month	Solar Heat Gain from Figs. 5.2 - 5.4 Btu/Month-ft^2 x 10^3 (1)	Adjustment Factors: Roof Overhang from Worksheet 5B (2)	Adjustment Factors: Off South Orientation: % Reduction from Sec. 5.3 (3)	Solar Heat Absorbed in MBtu/month A_{eff} x (1) x (2) x (3)
Aug.				
Sept				
Oct.				
Nov.				
Dec.				
Jan.				
Feb.				
Mar.				
Apr.				
May				
Jun.				
Jul.				

WORKSHEET 5A

ADJUSTED NET SOLAR GREENHOUSE HEAT GAIN

Month	Solar Heat Gain Absorbed (from Worksheet 5 of Greenhouse Calculations)		Monthly Heat Loss (Net Thermal Load) from Worksheet 4* MBtu/month		Net Heat Gain MBtu/month x Adjustment Factor ( )	=	Adjusted Net Solar Greenhouse Heat Gain
Aug.	________	-	________	=	________		________
Sept.							
Oct.							
Nov.							
Dec.							
Jan.							
Feb.							
Mar.							
Apr.							
May							
Jun.							
Jul.							

*For greenhouse heat loss to the outside only.

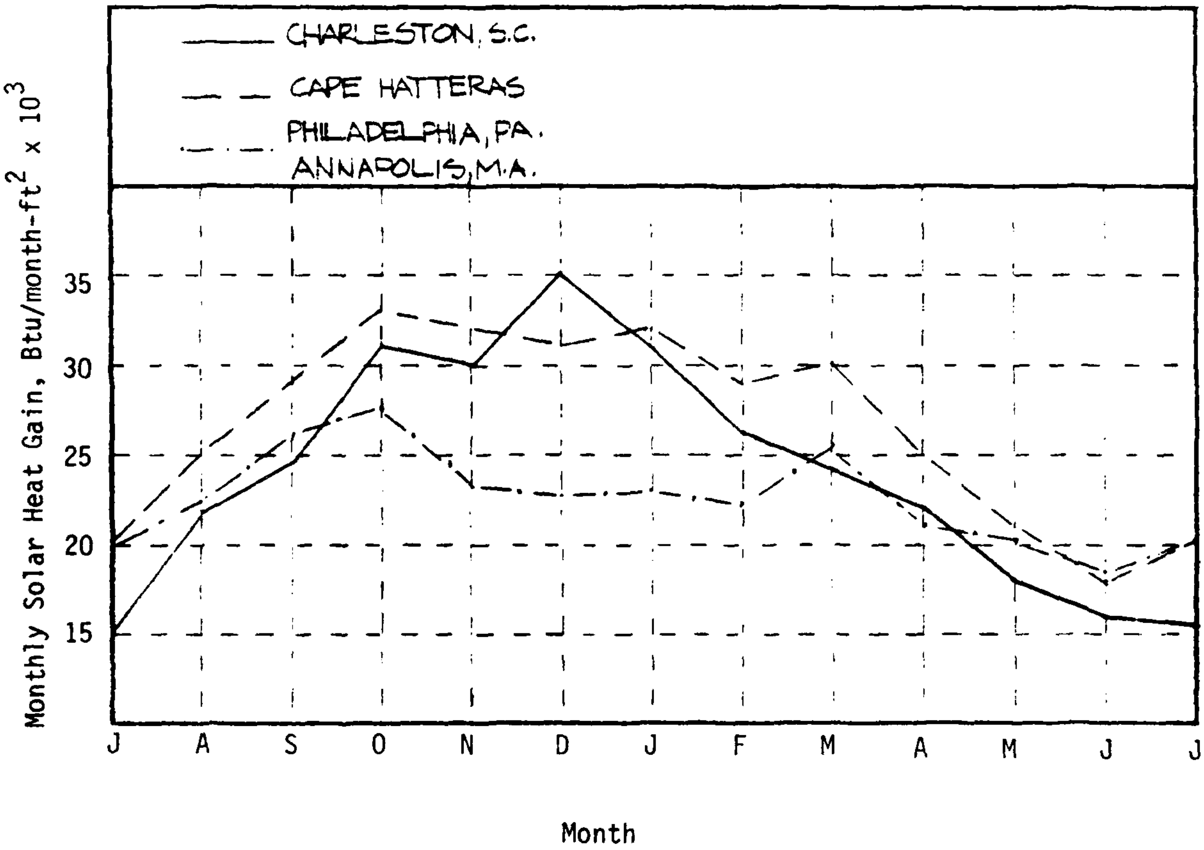


Figure 5.2 Monthly Average Solar Heat Gain Through Vertical South-Facing Single Glazing

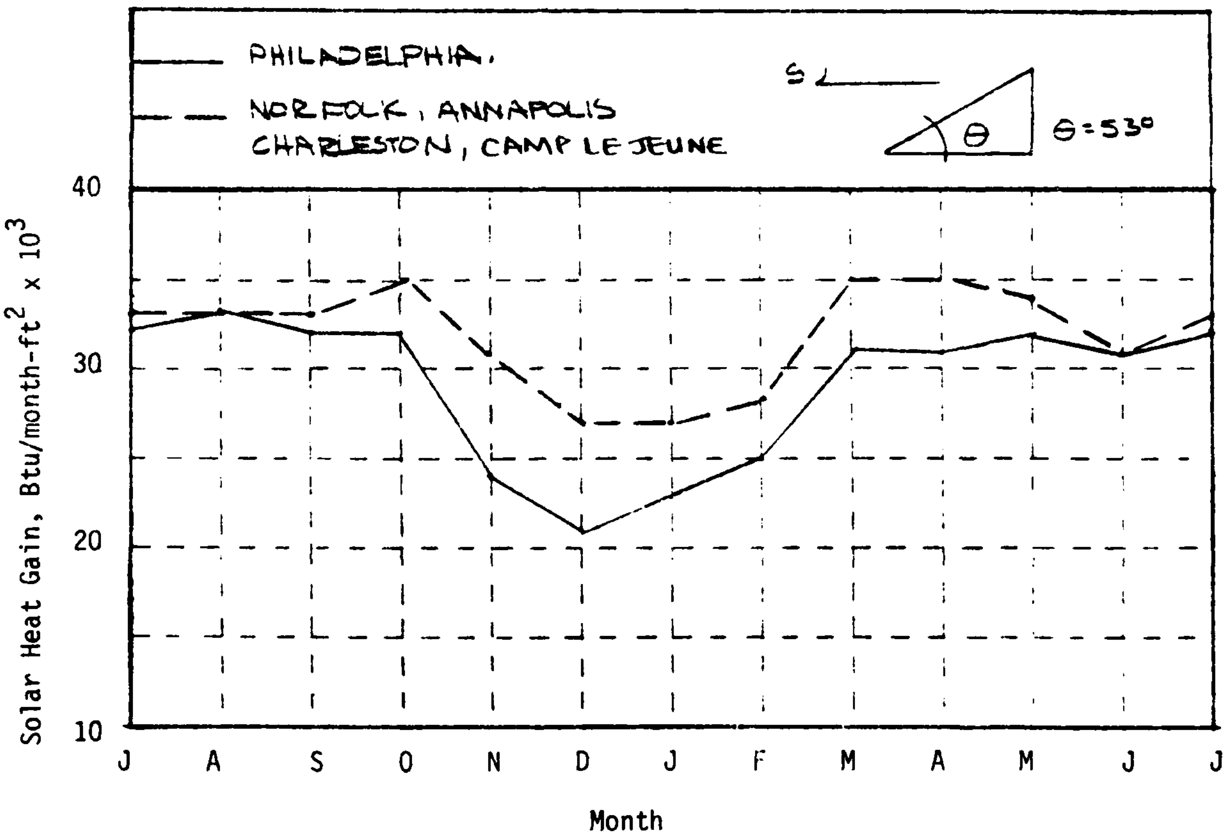


Figure 5.3 Monthly Average Solar Heat Gain Through South-Facing Single Glazing at 53° Tilt

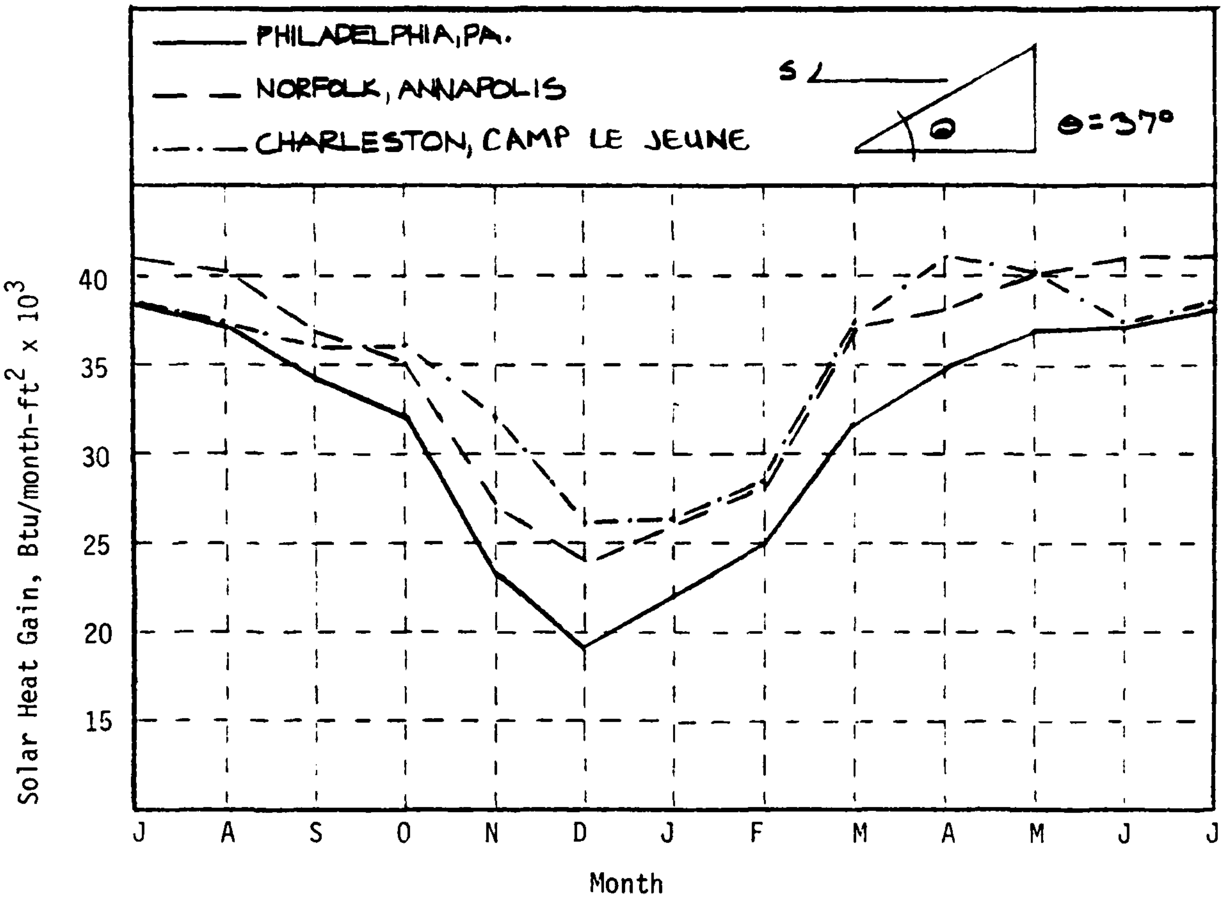


Figure 5.4 Monthly Average Solar Heat Gain Through South-Facing Single Glazing Tilted at 37^{0} (Temperate East Coast Locations)

5.2 Calculations and Adjustments for Roof Overhang

In case a roof overhang is used on the south side to give summer shading, the vertical length of the shadow cast in relation to the length of the horizontal roof projection is given in Table 5.2 for the different latitudes of East Coast Navy locations in temperate climates.

Once the overhang dimension has been tentatively decided on, it will have to be checked for winter shading by using Worksheet 5B. Table 5.3 lists the vertical length of the shadow cast per foot of roof overhang projection for different latitudes. When multiplied by the size of the overhang, the length of the shadow cast at noon is obtained and entered in Column (I). For example, at 37° N latitude, a 2.5 ft overhang would cast a 5.5 ft shadow in April. This illustrates how important it is to keep overhangs to a minimum in colder climates where solar heating is required into the late spring. Spring shading on south-facing vertical surfaces from a roof overhang can reduce heat gain to such an extent that more auxiliary heat will be required than in mid-winter.

Shading of the window should be checked for each heating month by calculating the shadow length. If much shading occurs, the solar heat gain from Figure 5.2 used on Worksheet 5 must be reduced for those months (or the overhang should be of a folding or removable type). Since the shadow is given for the noon hour when it is at its maximum, it is not necessary to take its full effect into account; about two-thirds will give a better approximation over the whole day. Note that the values in Tables 5.2 and 5.3 are only valid for south orientation. The shading factor (reduction in solar heat gain) in Column (M) of Worksheet 5B is entered in Column 2 of Worksheet 5.

TABLE 5.2

Summer Shading with Roof Overhang

(Ref. [6])

Latitude (A)	Length (ft) of Horizontal Projection to Cast Shadow on South Wall from 11 April - 1 September				
	(B)	4 ft Shadow	6 ft Shadow	8 ft Shadow	10 ft Shadow
33° N - Charleston	(C)	1.8	2.7	3.6	4.5
35° N - Camp LeJeune		2.0	3.0	4.0	5.0
37° N - Norfolk		2.2	3.3	4.4	5.5
39° N - Annapolis		2.4	3.6	4.8	6.0
40° N - Philadelphia		2.5	3.7	5.0	6.2

TABLE 5.3

Winter Shading With Roof Overhang (Noon)

(H) Height of Shadow Cast for Latitude per Foot of Projecting Overhang, ft					
Month	33° N Latitude	35° N Latitude	37° N Latitude	39° N Latitude	40° N Latitude
S	1.5	1.4	1.3	1.2	1.15
O	1.0	0.95	0.9	0.85	0.80
N	0.75	0.7	0.65	0.6	0.55
D	0.65	0.6	0.6	0.55	0.50
J	0.75	0.7	0.65	0.6	0.55
F	1.0	0.95	0.9	0.85	0.80
M	1.5	1.4	1.3	1.2	0.15
A	2.6	2.4	2.2	2.1	2.0
M					2.8

WORKSHEET 5B

CALCULATION OF SHADING WITH SOUTH ROOF OVERHANG

(A) Latitude of building site: _____ °N

(B) Length of summer shadow desired: _______ ft

(C) Size of roof overhang (projection from south wall)
from Table 5.2 (directly or interpolated): ___________ ft

(D) Height of lower overhang edge from finished floor: ____________ ft

(E) Distance from finished floor to top of glazing: __________ ft

(F) Vertical distance from top of glazing to roof overhang:
(D) - (E) = __________ ft

(G) Window or glazing height: ________ ft**

Month	Height of Shadow Cast, ft (H) x (C) = (I)	Effective Shadow Length, ft (J) = 2/3 (I)	Window Shading, ft* (K) = (J) - (F)	% Shading, (K)/(G) = (L)	Shading Factor, (M) = 1 - (L)
S					
O					
N					
D					
J					
F					
M					
A					
M					
J					

Enter Column (M) in Column 2, Worksheet 5.

* If (J) - (F) is less than zero, enter zero in Column (K).

** If window (glazing) height varies, a reasonable average can be assumed.

5.3 Influence of Off-South Orientation

In retrofit applications, the heat-gaining surfaces and glazing will not always be facing true south or nearly so. Figure 5.5 gives the percent of solar radiation striking a vertical wall, with the true south exposure receiving the monthly maximum or 100 percent (for 33°N and 40°N latitude). A linear interpolation may be made for other latitudes within this range. Note that deviations of ±30° receive nearly 90 percent of the mid-winter radiation; this percentage drops to about 75 for the SE and SW orientation and to 35 for E, W orientations. The percent reduction (or increase) is read from Figure 5.5 and entered in Column 3, Worksheet 5 in decimal form (i.e. 60% = 0.60). A slightly eastern orientation may be desirable where early morning heat gain is wanted and possible with climatic and topological conditions (i.e. no pattern of early morning fog or mountains to the east) and where the summer breeze is predominantly from an easterly direction. Because of the large heat gains on E and W facing walls in southern latitudes, an off-south orientation can pose a more difficult problem in the summer. Special attention will have to be paid to shading these surfaces in the summer without impeding natural ventilation. Roof overhangs are not useful in orientations more than about 20° off south, because they would have to be extremely large to be effective.

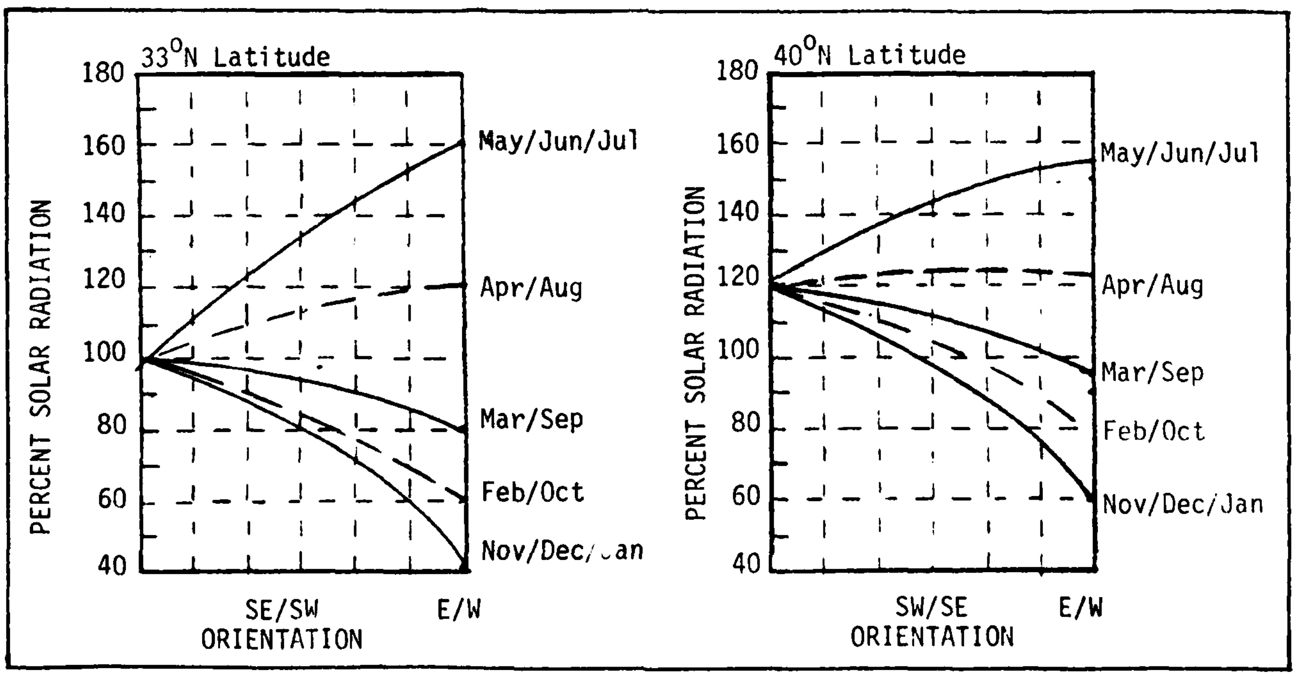


Figure 5.5 Percent of Average Solar Radiation Received on Vertical Walls Deviating from True South at 33° and 40° N Latitude (Ref. [12]).

5.4 Spacing for Sawtooth Clearstory Window Arrangements

If south-facing clearstory windows and/or solar collectors for water heating are arranged in more than one row, the spacing between these rows must be large enough to avoid shading the second row by the first row. The formula below can be used to calculate the length of the shadow for any obstacle that may be in front of the solar glazing, be it collector or window. For comparatively narrow obstructions, the solar altitude value at noon should be used; for shading by longer rows, a value earlier in the morning should be chosen. The formula for the spacing distance is:

$$d = h/\tan \alpha$$

where d, h and α are defined in Figure 5.6. The obstacle height can be taken off the design drawings. The sun altitude angles α for December (the worst

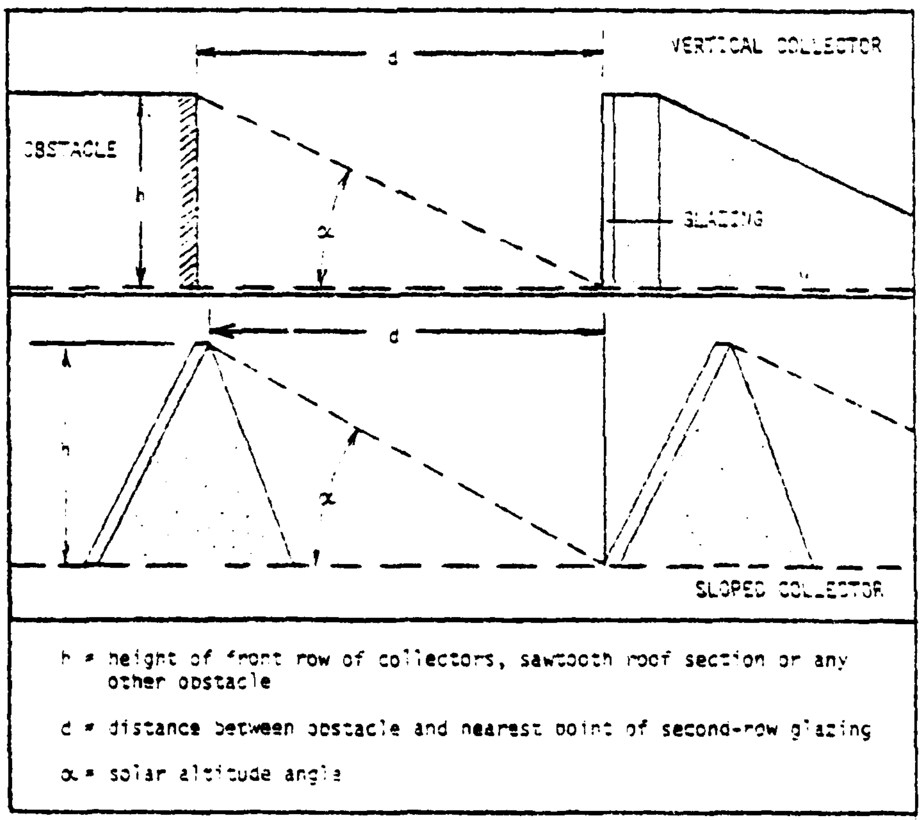


Figure 5.6 Definition of Symbols Used in Sawtooth Spacing Calculation

condition) for temperate East Coast locations and different times of day are listed in Table 5.4, together with the corresponding values for tan α.

For example, if the obstacle height of a long row is 6 feet, the spacing to the second-row glazing should be $d = 6/\tan 19° = 6/0.34 = 17.65$ ft for a building in Charleston, South Carolina, with no shading after 9 a.m. or $d = 6 \tan 21° = 6/0.38 = 15.8$ ft for a building in Philadelphia, Pennsylvania, with no shading after 10 a.m. If these spacing distances are too large, some shading after 10 a.m. may have to be tolerated or the clearstory windows or collectors can be raised some in the second row. Since this calculation was made for the month of December, any other time of the year will have less shading on the second row even very early in the morning.

TABLE 5.4
Sun Altitude Angles on 21 December
for Temperate East Coast Locations and
Different Times of Day, together with the Function tan α

Solar Time	40°N Lat		39°N Lat		37°N Lat		35°N Lat		33°N Lat	
	α	tan α	α	tan α	α	tan α	α	tan α	α	tan α
8 a.m.	5.5°	0.1	6°	0.11	7°	0.12	8.5°	0.15	10°	0.18
9 a.m.	14°	0.25	15°	0.27	16°	0.29	18°	0.32	19°	0.34
10 a.m.	21°	0.38	22°	0.40	23.5°	0.43	25°	0.47	26.5°	0.50
11 a.m.	25°	0.47	26°	0.49	28°	0.53	30°	0.58	32°	0.62
Noon	26.5°	0.50	27.5°	0.52	29.5°	0.57	31.5°	0.61	33.5°	0.66

5.5 Calculation of Building Auxiliary Load Profile

Worksheet 6 is used to determine the solar load ratio and ultimately the auxiliary load profile. Values for the net thermal load are transferred from Worksheet 4. The total solar heat gain for each month is the sum of all passive/hybrid absorbed solar heat figures from Worksheets 5 and the adjusted net heat gain from Worksheet 5A in the case of a greenhouse. The solar load ratio (SLR) is the total monthly solar heat gain divided by the monthly net thermal load. The solar heating fraction (SHF) is then obtained from the solar heating estimator (Figure 5.7) for the corresponding value of solar load ratio for each month. The monthly solar heating contribution is obtained by multiplying the SHF with the net thermal load. Finally, the auxiliary load profile is calculated by subtracting the solar heating contribution from the net thermal load.

Depending on the size of the house and its location, an auxiliary monthly load of 1 to 2 MBtu can easily be supplied with an efficient wood burner. Economically, it is probably not necessary to supply more than a solar heating fraction above 0.8 in the mid-winter months since the solar heat gain needed to increase the fraction above 80 percent is proportionally much larger than at lower SHF, and the added investment is most likely neither cost-effective nor necessary, since too much heat gain during the coldest month will lead to increased likelihood of overheating, especially in the fall. More importantly even, the calculated auxiliary load will occur only in the coldest years, because it is impossible to accurately take the "comfort factor" into account in these calculations. However, from experience it has been found that passively-heated homes feel comfortable at much lower interior air temperatures than do conventionally heated houses, thus less auxiliary heat will be needed in the actual case than is indicated by the calculations, especially for the designs that incorporate some type of zoning where bedrooms would remain unheated when the auxiliary is used.

It is very important in locations with long cool winters to choose the auxiliary wood burner (References [14, 15]) or other backup system with great care. If a conventional system is used, it must be sized correctly for the small loads of these well-insulated houses. Reference [4] contains a discussion of auxiliary heating in New Mexico; much of the discussion also applies to conditions elsewhere. The future availability of the auxiliary energy source must be considered. Wind generators may be attractive and economical in cold, windy locations.

WORKSHEET 6

CALCULATION OF BUILDING AUXILIARY LOAD PROFILE

Month	Net Thermal Load (from Worksheet 4) (A)	Total Solar Heat Gain (from Worksheet 5) (B)	Solar Load Ratio (SLR) (B) ÷ (A) (C)	Solar Heating Fraction (SHF) (from Fig. 5.7) (D)	Solar Heating Contrib. (D) x (A) (E)	Auxiliary Load Profile (A) - (E) (F)
Aug.						
Sept.						
Oct.						
Nov.						
Dec.						
Jan.						
Feb.						
Mar.						
Apr.						
May						
Jun.						
Jul.						
TOTAL	MBtu				MBtu	MBtu

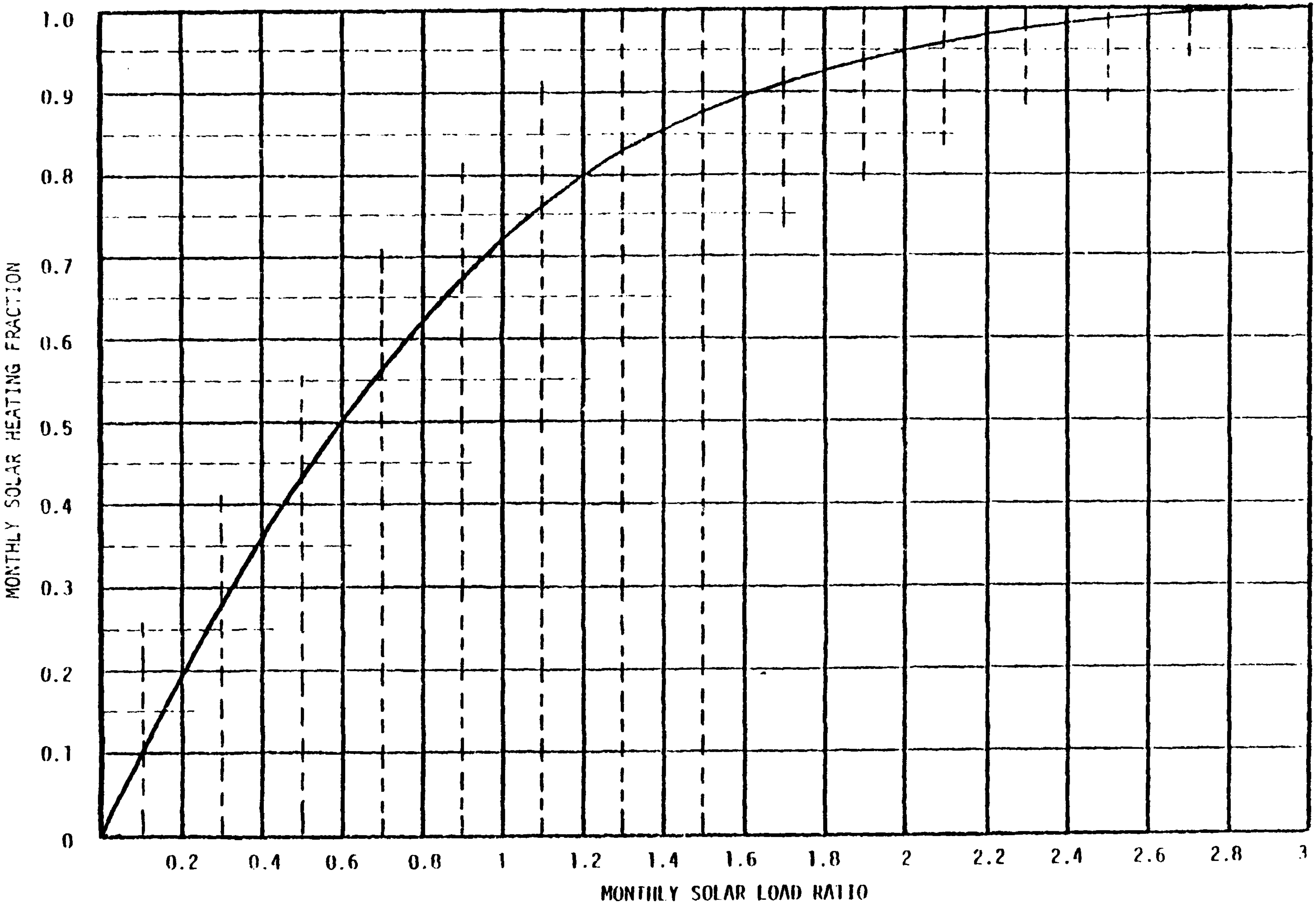


Figure 5.7 Monthly Passive Solar Heating Estimator

6. GLAZING AND STORAGE CALCULATIONS

A very rough estimate of the ratio of south-facing window area to floor area for direct gain houses is given by the following:

For cold climate, glass area/floor area = 0.2 - 0.3
For moderate climate, glass area/floor area = 0.15 - 0.25
For warm climate, glass area/floor area = 0.1 - 0.15

These values are given for houses with maximum insulation, adequate mass, good heat distribution and small auxiliary heaters. Approximately the same relationship should also hold for each solar-heated space or room; however, the location of each room and its use must be taken into consideration. For instance, kitchens with many internal heat sources will need less solar heat than living areas, and sleeping areas used only at night may also remain cooler. Reference [1] gives many additional rules of thumb for glazing and storage sizing.

The importance of good heat distribution together with an adequate amount of mass for the specific climatic conditions cannot be overemphasized. For example, south-facing rooms should not be too small and should have large door openings as well as masonry walls connecting to the north-side rooms, if they are not open areas altogether. The storage mass should have a large surface area (with a thickness from 6 to 18 inches for masonry) well distributed over the rooms. It does not have to be in direct sunlight, although the effectiveness of direct gain is increased (and less mass is required) if at least a portion of the heat storage mass receives direct sun in the mid-winter months during a good part of the day.

The amount of storage mass will determine the comfort in the house, i.e. the daily temperature swing that will be experienced and the heat loss over a completely cloudy day. Table 6.1 gives a tabulation of storage mass required per temperature swing of the storage mass and the maximum solar heat gain per day for 100 square feet of south-facing windows. For masonry walls that are not directly exposed to the sun, a temperature rise of around 5^{o}F would be comfortable; for mass exposed to the sun, a temperature rise of 20^{o}-25^{o}F is not unusual. For a combination, a ΔT of 10^{o}F maximum is a good value to be assumed for the calculations and design.

Worksheet 7 can be used to tabulate these calculations for each room. Note that the storage volume will have to be adjusted for the actual glazing in each room (net area of glass), since it is listed in Table 6.1 on the basis of a 100 square foot window area. To calculate the maximum temperature drop in the house for an average January day without any solar gain or auxiliary heating, the formula in the lower half of Worksheet 7 can be used. Values for heat capacity of storage materials are listed in Table 6.2. A calculated drop of 8^{o}F or less is considered to be adequate for a direct-gain house in a sunny climate. A much larger drop indicates that some auxiliary heating will be required on most cloudy days. Actual performance will be better than the calculations indicate in many cases, since nights during cloudy periods have higher average temperatures than clear nights, and also because some solar radiation is received even during cloudy conditions. For a second, consecutive day, the temperature drop would be somewhat less, because this type of heat loss follows an exponential curve.

For fully exposed south-facing vertical double glazed windows at 40^{o}N latitude, the maximum clear-day daily heat gain in December/January is about 1250 Btu/ft^2-day with snow on the ground. For sloped double-glazed windows and windows with reflectors, it can range up to 1500 Btu/ft^2-day at 40^{o}N latitude. At 32^{o}N latitude, the maximum clear-day daily heat gain in December/January through vertical double-glazed windows is about 1375 Btu/ft^2day (1500 Btu/ft^2-day with snow). For sloped single-glazed skylights, it can range up to 1750 Btu/ft^2-day in February. To calculate an adequate amount of storage, determine the daily solar heat gain per square foot for the design, then choose a value for ΔT and read the volume of storage required from Table 6.1. This value must be adjusted for the room by multiplying by the south window area of the room and dividing by 100. More mass than this will give a lower ΔT. If only a small amount of space is available, water exposed to the sun directly behind the glazing will use the least volume; if space is not critical, mass walls can be used; they will supply support, ease of maintenance and soundproofing. Phase-change materials (eutectic salts) may be available commercially in the future for heat storage that will be able to store large amounts of heat in a small volume (Reference [2]).

When the design of the home has been completed, the storage mass in the building should be checked once more. If the mass is scanty (especially in areas with many clear days in the winter), the daily temperature levels in the home will fluctuate wildly; if the mass is too large (especially in areas with many cloudy days in the winter), it will be difficult to warm up the home again after a long period of cloudy weather, and too much auxiliary heat will be diverted to recharging the storage. It will not be economical to spend money on excessive storage. In houses where solar is not expected to supply nearly the entire daily net heat load (that is, some auxiliary heating is acceptable for most days), storage can be somewhat higher; it will be useful for load management and to avoid rapid cooling in areas where supply interruptions of the auxiliary fuel are likely.

Completing Worksheets 1 through 7 with the data from the preliminary design sketches should give the designer a good idea of the expected performance of the planned passive solar building* and the influence of the different design components and their relationships. The procedure should be repeated each time changes are made and finally with the exact dimensions off the finalized blueprints and building specifications. Window dimensions especially seem to change at the last minute depending on what is available at the local supplier at a good price or in order to comply with codes when getting the building permit. The U-value of the wall and roof materials and insulation finally chosen may also vary from that assumed for the design calculations, depending on market conditions, especially if last-minute substitutions have to be made because of shortages or in a more fortunate case because an unexpected bargain becomes available. Calculations should be redone if the U-values of walls and/or roof are higher than those used in the calculations, to check if additional solar heat should be provided. On the other hand, if the U-values are considerably lower than those used in the calculations, it may be possible to reduce solar window size or relax some other design specifications as compensation. Since the heat loss of the building is very much influenced by the R-factor of window night insulation and since this component will be one of the last to be chosen and installed, adjustments can be made here if heat losses have changed because of substitutions which have arisen during the building phase.

*If actual operating conditions (i.e. infiltration rate) will closely correspond to the assumptions made in the calculations.

WORKSHEET 7
GLAZING AND STORAGE CALCULATIONS

Daily Maximum Solar Heat Gain: ________

Room	South Glazing ft^2	Floor Area ft^2	Designed Storage ft^3	Storage Volume per $100\ ft^2$ of Glazing ft^3	Temp. Swing °F
.....					
.....					
.....					
.....					
.....					
.....					
.....					
.....					
	____	____	____	____	
TOTAL	====	====	====	====	

Check for temperature drop during a completely cloudy day (24-hour period):

$$\text{Maximum } \Delta T = \frac{\text{Net January Thermal Load*}/31}{\text{Total Volume x (Heat Capacity of Storage Material)**}}$$

$$\Delta T = \frac{(\qquad\qquad)}{31\ (\qquad\qquad)\ (\qquad\qquad)} = \underline{\qquad\qquad}\ ^\circ F$$

*From Worksheet 4.
**From Table 6.2.

Table 6.1

Mass Required to Store Solar Heat Gain Through Windows

Maximum Daily Solar Heat Gain	Temperature Swing of Thermal Mass	Volume of Storage per 100 sq. ft of Window Area		
		Water		Concrete
Btu/ft^2-day	ΔT, °F	ft^3	gal.	ft^3
500	5	160	1200	415
	10	80	600	210
	15	55	400	140
	20	40	300	105
	25	30	225	85
750	5	240	1800	625
	10	120	900	315
	15	30	600	210
	20	60	450	155
	25	50	375	115
1000	5	320	2400	830
	10	160	1200	420
	15	110	825	280
	20	80	600	210
	25	60	450	170
1250	5	400	3000	1050
	10	200	1500	520
	15	130	1000	350
	20	100	750	260
	25	80	600	210
1375	5	440	3300	1150
	10	220	1650	585
	15	145	1100	385
	20	110	825	285
	25	90	675	230
1500	5	480	3600	1250
	10	240	1800	630
	15	160	1200	420
	20	120	900	310
	25	100	750	250
1750	5	560	4200	1460
	10	280	2100	730
	15	190	1425	490
	20	140	1050	360
	25	110	825	290

TABLE 6.2

Heat Transfer Characteristics of Masonry Storage Materials Compared to Water, Wood and Steel

Material	Specific Heat Btu/lb-°F	Density lb/ft^3	Heat Capacity Btu/ft^3-°F	Conductivity $\frac{\text{Btu-in.}}{\text{hr-°F-ft}^2}$
Adobe	0.22	90-105	20-23	4
Brick	0.21	110-130	23-27	5
Brick with magnesium additive	0.2	120	24	26
Concrete (Stone, Sand)	0.16	140	22	12
Concrete (Cinder Block)	--	80	--	2.5
Gravel (30% voids)	0.21	115	24	2.6
Earth	0.21	95	20	6
Pumice	--	49	--	1.3
Sand	0.2	100	20	2
Stone	0.2	165	33	11-12
Steel	0.12	490	59	310
Wood	0.6	30	18	0.8-1.1
Water	1.0	62.4	62.4	4

7. ENERGY SAVINGS CALCULATIONS

Since many people are not only interested in knowing how much auxiliary energy will need to be expended to heat the designed building, but also in how much energy is saved (in order to calculate the cost-effectiveness of the passive method), a brief discussion of the topic is included here. Unfortunately, the problem is rather complex, since results depend on the performance calculation method used [16] and on the design of a "reference" building. Since a passive design is a combination of very good insulation, sufficient storage mass and correct choice and placement of heat-gaining windows, walls, roofs and spaces, it is very difficult to determine what the conditions would have been for a "similar" building but without passive heating. Would such a building still have the same shape, orientation, roof line, volume, size, floor plan, etc., since these were to a very large extent chosen with passive heat gain in mind? Thus, for the sake of simplicity and uniformity, it is proposed here that the minimum U-values for the building's design be used as specified in the local building code. Also assumed are a standard ceiling height of 8 feet unless the reference building would definitely have been designed with a different ceiling height. A square floor plan with windows 10 percent of the floor area and distributed equally in all four directions is assumed also, if the passive solar building has a compact, rectangular shape. If the passive house has a more complicated floor plan, the same outline should be assumed for the reference building also. The main reason for these assumptions is that up to now buildings on the whole have been oriented with complete disregard to solar gains, so that on an average, just as many windows and building orientations are found in each direction.

Worksheet 8A can then be completed in a manner similar to the calculation procedure for passive houses, though the computations are somewhat simplified. The same values for heating degree days and solar heat gain should be used as in the passive computations. Internal heat gain is not subtracted in conventional houses, since it is assumed that this heat will help raise room temperatures from the 65^{o}F design temperature to a more comfortable 70^{o}F or so, in contrast to passive solar homes which are quite comfortable at 65^{o}F air temperature. Effective window area for south-window solar gain is calculated in the same way as for the passive design and then multiplied by one half,

since some of these windows may be shaded. The auxiliary load of the solar design from Worksheet 6 can then be compared with the heating load of the reference building.

On Worksheet 8B, the heating load of the reference building from Worksheet 8A is listed first. Subtracted from this is the auxiliary load of the passive design, as calculated on Worksheet 6. This will give the heat saved in MBtu by using the passive design. If the passive design uses fans and other motorized equipment, these power requirements will have to be subtracted from the gross heat saved to get a true picture of the real savings between the two buildings. This power usage is usually obtainable in kWh; for conversion to MBtu, it must be multiplied by 0.0034 before it is listed on Worksheet 8B.

The energy savings depend on the fuel that is being replaced by solar. Energy savings can be calculated for the most commonly available energy source in the area or for all of them. The results of course will only reflect savings based on the current price of these fuels. Solar energy is neither subject to price escalation nor inflation once the equipment is installed or the structure is built. With the steep increases in the cost of fossil fuels, the savings due to solar can be expected to increase dramatically if considered over the life of the structure (which can be as much as 50 years or more for a well-built house). In order to express the cost per unit energy in dollars per million Btu, the cost is multiplied with a conversion factor (which also includes a multiplier for efficiency).

For example, if electricity were to heat the reference building, the cost in cents/kWh is multiplied by 2.93 to get the cost in $/MBtu (since 1 MBtu = 293.1 kWh) and by the net energy saved to get the total monthly savings in dollars.

If gas is assumed to be the fuel for heating the reference building, the net heat saved is multiplied with the cost of gas ($/MCF) times 1.7 to take burner efficiency into account. Natural gas is sold in units of one thousand cubic feet (or MCF) which have a heat content of around 1 MBtu. At present, most utilities have a sliding price scale for their energy sales; this means that

WORKSHEET 8A

CALCULATIONS FOR REFERENCE BUILDING

Building Location: Zone:

Floor Area:_____ft^2 = (_____$ft)^2$; Perimeter = _____ft;

S. Window Area = (0.1)(A)+4 = _______ft^2;

Effective Window Area = ½( )( )( ) = _____ft^2

Building Skin Conductance (Btu/hr-°F):

Total Walls:	U-Value x Area = ( )x( )=	_____
Total Windows and Doors:	U-Value x Area = ( )x( )=	_____
Roof:	U-Value x Area = ( )x( )=	_____
Floor: (See Section 4.1)	= ( )x( )=	_____
	TOTAL	$\boxed{}$

Infiltration: Volume x C_p x ACH = ( ) x ( ) x 1 = $\boxed{}$

Modified Building Heat Loss Coefficient C_B

= 24 (Skin Conductance + Infiltration) = 24[(+)] = $\boxed{}$

C_B/A = $\boxed{}$ Btu/D.D.-ft^2

Heat Load Calculations(MBtu): Gross Heating Load minus Solar Heat Absorbed is equal to Net Heating Load

Month	Degree Days	Gross Heating Load	Solar Gain	Solar Heat Absorbed	Net Heating Load
Aug.					
Sept.					
Oct.					
Nov.					
Dec.					
Jan.					
Feb.					
Mar.					
Apr.					
May					
Jun.					
Jul.					

WORKSHEET 8B

HEAT SAVINGS CALCULATIONS FOR PASSIVE DESIGN*

Month	Reference Bldg. Heating Load	Passive Solar Building Aux. Load	Gross Heat Saved	Parasitic Power (See Footnote), kWh x 0.0034	Net Energy Saved	Cost of Energy Saved: ELECTRICITY: cents/kWh x 2.93 GAS: $/MCF x 1.7 ** OIL: $/gal x 14.4 *** WOOD: $/cord x 0.11 **** =____ $/MBtu x Net Savings =			
	MBtu/mo.	MBtu/mo.	MBtu	MBtu	MBtu	$			
						EL	GAS	OIL	WOOD
Aug.	( ) -	( ) =							
Sept.									
Oct.									
Nov.									
Dec.									
Jan.									
Feb.									
Mar.									
Apr.									
May									
Jun.									
Jul.									
TOTAL									

*Does not include savings for solar water heating (or summer cooling).

**60% efficiency.

*** 1 MBtu = 7.2 gal. heating oil, 50% efficiency.

****Average of 20 MBtu per cord of wood depending on type [15] and 45% efficiency.

Add electricity needed to run the conventional furnace; substract the electricity needed to operate fans in the passive design.

large users pay less per unit than do small users. Thus it may be somewhat difficult to obtain exact quotes for gas prices per MCF for these calculations. The situation is somewhat similar for electricity costs also. If you have recent utility bills at hand, you may calculate an average price from these. Do not forget to include taxes and any charges for fuel cost adjustments included on the bill. The last column in Worksheet 8B then represents the savings in an average heating season with present energy prices. At present, gas prices in many areas are still relatively low (and the savings correspondingly small); this situation, however, can change rather quickly once natural gas prices become deregulated. Electricity is expensive, because it is a secondary energy source which has been generated from a primary source (gas, oil, hydro, wind, nuclear, coal etc.). This conversion, when using fossil fuels, is only about 30% efficient. Electricity is also a high-temperature, high-quality energy source, and its use for heating is in most cases not appropriate, unless it is generated from a renewable source such as a wind machine and its supply is abundant and reliable.

Since energy prices are expected to double in another ten years or less, it can be seen that the savings will increase in future years to make the passive design even more worthwhile. To this, add the benefit of a healthier environment (inside and outside the house and in the community), possibly less maintenance and less noise because of the mass, a longer life for the building because of its quality construction, and federal* and state** solar tax rebates, and it can be seen that even with somewhat higher construction costs the well-designed and well-built passive building will be an excellent investment indeed. The passive house will also be (and feel) so much warmer, especially since people in conventional homes are turning their thermostats down to save energy and money.

If you have difficulties with this calculation procedure, it may be helpful if you could attend a solar workshop which is held periodically in different

*Federal legislation now in Congress may soon allow tax rebates for the passive components of a building.

**State solar tax rebates vary from state to state. Some counties and municipalities may also have special benefits for solar construction, i.e., exemptions from sales tax, property tax, etc.

cities around New Mexico; these workshops are sponsored and taught by the New Mexico Solar Energy Institute in cooperation with the New Mexico Solar Energy Association (NMSEA). It may also be helpful for you to study a complete example design together with completed worksheets. A separate brochure describing the available example designs is available from the New Mexico Energy Institute, Box 3SEI, New Mexico State University, Las Cruces, NM 88003 (Report NMEI 22-2). It would be best to study a design which most nearly corresponds to your own climatic region and features the passive solar methods you are considering for your own design. If your design incorporates a Trombe wall or greenhouse, attending a hands-on workshop conducted by the New Mexico Solar Energy Association in Santa Fe or its affiliated local societies is highly recommended, or similar workshops may be held by solar societies in your area. A completed set of worksheets is attached in the Appendix, giving the calculations for a direct-gain passive solar design for Wilmington, North Carolina (2400 H.D.D.).

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16. L. Palmiter and B. Hamilton, "A Comparison of Performance Factors for Passive Solar Heating," Southwest Bulletin, New Mexico Solar Energy Association, Vol. 4, No. 1, January/February 1979, pp. 18-22.

ADDITIONAL RECOMMENDED READING

17. Rick Fisher and Bill Yanda, Solar Greenhouse, John Muir Publications, Santa Fe, NM 87501, 1976.

18. D. A. Bainbridge, "Water Wall Passive System - For New and Retrofit Construction," Proceeding of the 3rd National Passive Solar Conference, American Section of ISES, San Jose, CA, 11-13 January 1979, pp. 473-478.

19. Stephen Weinstein, Architectural Concerns in Solar System Installations, Prepared for the Department of Energy under Contract No. E-77-C-01-2522; available from National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Rd., Springfield, Virginia 22161 (Solar/0801-79/01, Distribution Category UC-59).

20. James L. Easterly, Engineering Concerns in Solar System Design and Operation, prepared for the Department of Energy under Contract No. EG-77-C-01-2522; available from National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161 (Solar 0511-79/01, Distribution Category UC-59).

21. Franklin Research Center, Installation Guidelines for Solar DHW Systems in One- and Two-Family Dwellings, Contract H-2377, Report HUD-DR-407, Superintendent of Documents, U. S. Government Printing Office, Washington, DC 20402, April 1979.

22. Sunset Books, Homeowner's Guide to Solar Heating, Lane Publishers, Menlo Park, California, 1978.

23. Bruce Anderson and Michael Riordan, The Solar House Book, Chesire Books, Harrisville, New Hampshire, 1976.

24. Bruce Anderson, Solar Energy: Fundamentals in Building Design, McGraw-Hill, New York, 1977.

25. D. Wright, Natural Solar Architecture, Van Nostrand Reinhold Co., New York, 1978.

26. A Survey of Passive Solar Buildings, AIA Research Corporation, Stock No. 023-000-00437-2, Superintendent of Documents, Government Printing Office, Washington, DC, 20402, $3.75, February 1978.

27. In The Bank---or Up the Chimney, Abt Associates, Inc.; Stock No. 023-000-00411-9, Superintendent of Documents, U. S. Government Printing Office, Washington, DC, 20402, 1977, $1.70. (Information on insulation.)

28. William A. Shurcliff, New Inventions in Low-Cost Solar Heating (100 Daring Schemes Tried and Untried), Brick House Publishing Company, Harrisville, NH, 03450, 1979.

29. Dan Scully, Don Prowler, Bruce Anderson, The Fuel Savers, A Kit of Solar Ideas for Existing Homes, Brick House Publishing Company, Harrisville, NH 03450, 1978.

30. Norah D. Davis and Linda Lindsey, At Home in the Sun, Garden Way Publishing, Charlotte, Vermont, 05445 (paperback), 1979. (This book is about solar home living experience, including performance and cost.)

31. William A. Shurcliff, Thermal Shutters and Shades: Over 100 Schemes for Reducing Heat Loss Through Windows, Brick House Publishing Co., Inc., Andover, Mass., 1980.

32. Passive Solar Design Handbook, Vol. 1 (Bruce Anderson): Passive Solar Design Concepts; Vol. 2 (Doug Balcomb, et al.): Passive Solar Design Analysis, DOE/CS-0127 US 59, 1980. Available from National Technical Information Service, U.S. Dept. of Commerce, 5285 Port Royal Rd., Springfield, Virginia, 22161. Cost: $13.25 for Vol. 1, $14.00 for Vol. II.

33. William A. Shurcliff, Superinsulated and Double Envelope Houses: A Preliminary Survey of Principles and Practice, 1980; Available from the author, 19 Appleton Street, Cambridge, Mass., 02138, $10 (payment enclosed), $12 (billed).

ADDITIONAL SOURCES OF INFORMATION

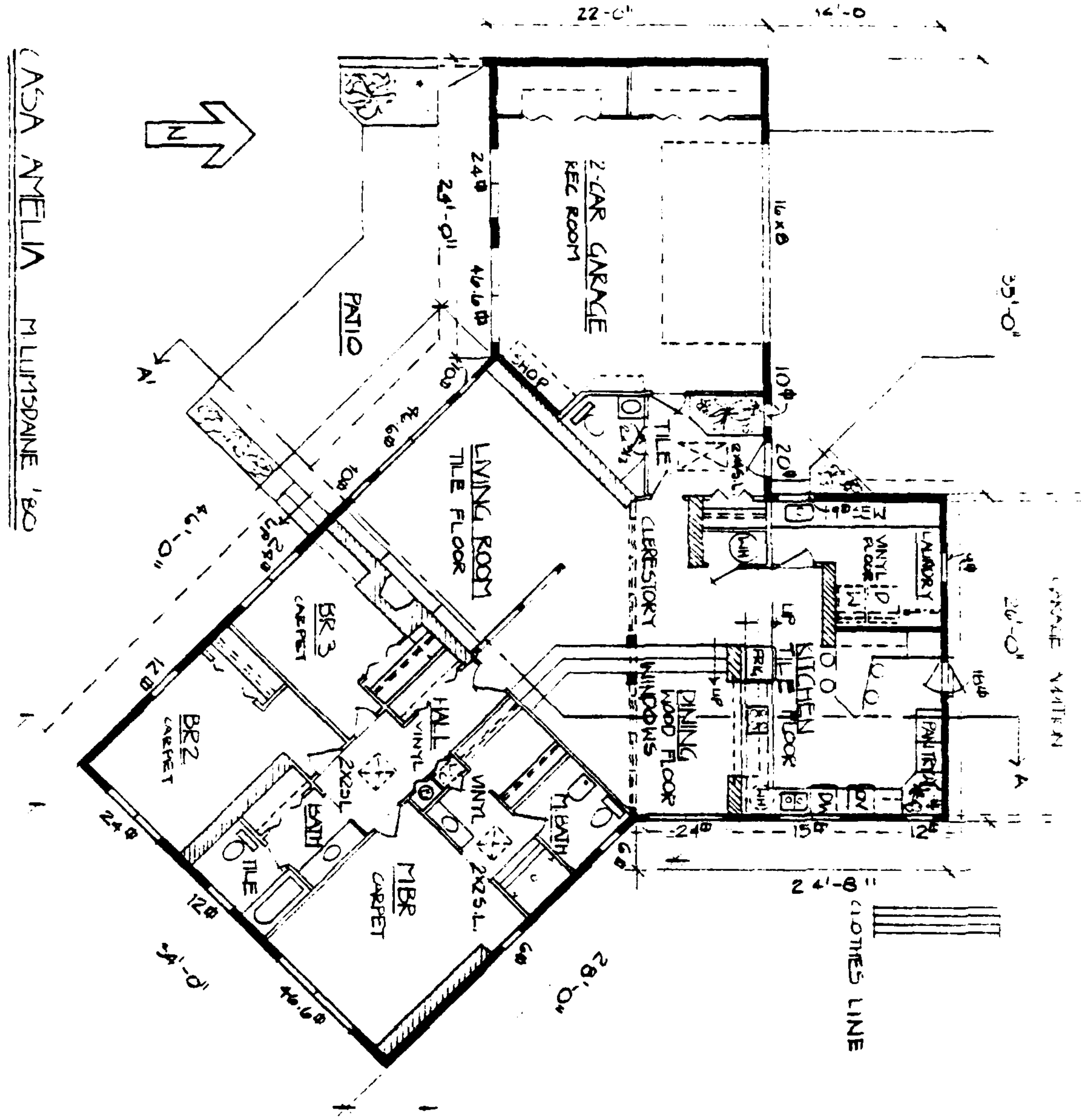
National Solar Heating and Cooling Information Center P. O. Box 1607, Rockville, MD 20850	toll free 1-800-523-2929
(U.S.) Solar Energy Research Institute (SERI) 1536 Cole Boulevard Golden, CO 80401 (D.O.E. - funded research)	(303) 231-1000
Solar Lobby 1001 Connecticut Avenue, NW, 5th floor Washington, DC 20036 (polictical action group concerned with solar legislation at the federal level)	(202) 466-6350

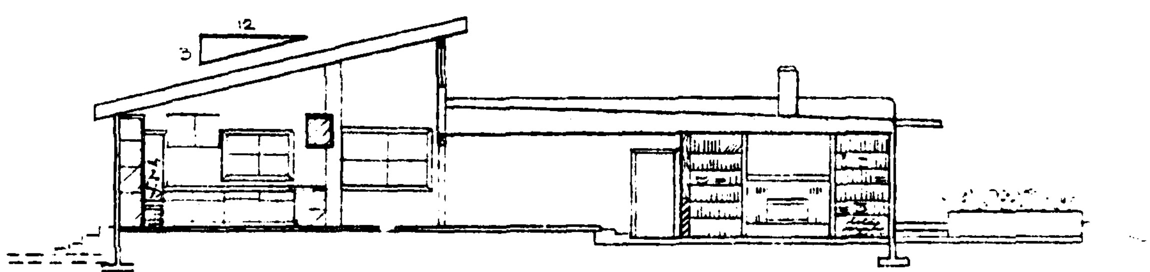
TVA Passive Solar Home Plans (4100 H.D.D. climate) give excellent construction details on Trombe walls, etc. Information may be obtained from Citizens Action Lines (615) 632-4100.

Solar Age Magazine, Solar Products Specifications Guide, Solar Vision Inc., Harrisville, NH, 03450; 6 updates per year, $100.

APPENDIX

DESIGN AND CALCULATION EXAMPLE FOR TEMPERATE CLIMATE


CASA AMELIA
M. LUMSDAINE '80
2-CAR GARAGE
REC ROOM
PATIO
SHOP
LIVING ROOM
TILE FLOOR
CLERESTORY WINDOWS
DINING
WOOD FLOOR
KITCHEN
TILE FLOOR
LAUNDRY
VINYL FLOOR
PANTRY
BR 3
CARPET
BR 2
CARPET
HALL
VINYL
BATH
TILE
M. BATH
VINYL
MBR
CARPET
CLOTHES LINE
22'-0"
14'-0
24'-0"
35'-0"
26'-0"
46'-0"
24'-8"
28'-0"
34'-0"



SECTION A-A'

WORKSHEET 1A

DESIGN INFORMATION

CASA AMELIA

1. Location of building: WILMINGTON, N.C. Altitude: SEA LEVEL 35°N
2. Building type (one or two story, split-level, etc.): ONE STORY, SPLIT LEVEL
3. Roof shape: FLAT AND SHED
4. Lot size: ________ Special features: OFF SOUTH ORIENTATION
5. Lot orientation (in which direction will the house face the street?): N
6. Building setbacks (check with local codes): ________
7. Zoning restrictions and covenants: ________
8. Lot access: NORTH OR WEST
9. Utility access: ________
10. Lot slope, water runoff (erosion?), berming: SLOPE DOWN TO WEST BERMING ON EAST
11. Predominant direction of winter wind: NW Velocity: 9 mph average
12. Predominant direction of summer breeze: SW Velocity: 9 mph average
13. Direction of best view: EAST, SOUTHWEST
14. Direction of worst view: ________
15. Shading from neighboring houses, trees, etc.: ________
16. Approximate floor area: 2150 + 590 GAR. Heated basement? NO
17. Number of occupants: ________
18. Number of bedrooms, baths: 3 BEDROOMS, 2+1/2 BATHS
19. Other living spaces wanted: DININGROOM, SEWING AREA.
20. Life style of occupants and special needs (i.e. play area for children, space for entertaining, hobbies; space used during day, evening; special storage requirements; handicaps): LOTS OF STORAGE, GARAGE WORK SHOP, (FUTURE REC. ROOM), PLANTER AREA, NICE DINING/LIVING AREA, SEPERATE BREAKFAST NOOK, FUTURE GARAGE ACCESS FROM KITCHEN
21. Preferred patio location, other outdoor recreation areas: SOUTHWEST OFF LIVINGROOM, PRIVATE MASTER BEDROOM COURTYARD.
22. Occupants like the following features: ________
23. Occupants dislike the following features: ________

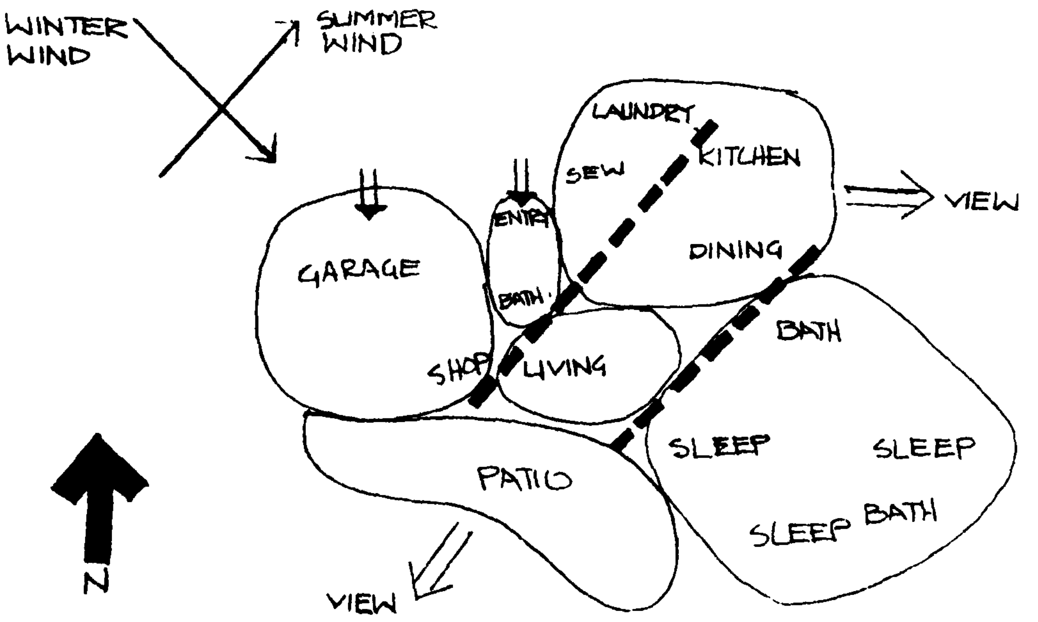
WORKSHEET 13

SPACE RELATIONSHIP DIAGRAM

CASA AMELIA

Floor area: 2070 (EXCLUDE ENTRY) sq. ft.

Sketch the location of the main entry and the living, cooking, eating and sleeping areas; then mark the major wind directions and use baths, utility, storage areas and garage as buffer zones against winter winds and summer heat. Indicate the zoning barrier (▪ ▪ ▪) and tentatively mark the location of auxiliary heat sources (✷). Areas thus marked will need to be designed so that they can be completely closed off from the remaining sections of the house during periods when auxiliary heating is necessary. Finally, show the direction(s) of the best view (and, optionally, undesirable views which will need to be screened).



WORKSHEET 1C

ADDITIONAL INFORMATION AND CHECKLIST FOR ENERGY CONSERVATION

CASA AMELIA

	Building orientation is within 5° E or W of South.
✓	Major axis runs east-west.
✓	Windbreaks are provided against winter and spring storms.
✓	Windows are of double or triple-glazed wood-frame (or equivalent) casement, single- or double-hung type? DOUBLE GLAZED CASEMENT
✓	Window areas to the north, east and west are minimized.
✓	Windows allow sufficient natural summer ventilation.
✓	Windows are insulated at night by (insulated drapes, shades, interior or exterior shutters): WINDOW QUILTS, VENETIAN BLINDS, SUN FLAKE WINDOW.
✓	Passive solar mechanisms included in the design are: S.E. + S.W. FACING GLASS AND SOUTH FACING CLERESTORIES FOR DIRECT GAIN
✓	Storage mass is located at: N.W. LIVINGROOM WALL + FLOOR; MR. BR. N.E. WALL; BR. 2-NE WALL; BR. 3 FIREPLACE WALL; KITCH + HALL WALLS + FLOOR.
✓	Are fans used for heat distribution: YES Where? CEILING FAN IN DININGROOM OR LIVINGROOM.
	Is there a solar greenhouse? NO
✓	Are there well-lighted spaces in the house for plants? YES
✓	Can sources of humidity in the house be vented easily? YES
✓	Is the main entry an air lock in the winter or breezeway in the summer? YES Do other entries have air locks or storm doors? YES SCREEN DOOR TO GARAGE, LAUNDRY & KITCH. DOORS.
✓	Can heated living areas be closed-off from sleeping areas? YES
✓	What type backup heater is planned? HEAT CIRCULATING FIREPLACE
✓	Will a solar water heater be used? YES What type? ______
✓	Solar tank location, size: HALL 80 to 120 GALLON TANK.
✓	Collector location: ROOF Type: ______ Area needed: 20 ft²/person
	Heat exchanger(s): ______
	Collector slope (approximately equal to latitude +10° is best): ___
✓	Backup water heater, type, size, fuel: 20 GAL. FOR DISHWASHER, 40 GAL. FOR BATH.
✓	Energy-efficient applicances to be used are: MICROWAVE, RANGE, DISHWASHER, REFRIGERATOR, SELF CLEANING OVEN.
✓	Fluorescent lights are to be used in: KITCHEN, BATHROOM, LAUNDRY, GARAGE, SEWING, HALL BR. WING.
✓	Fireplace has chimney on interior wall and is equipped with fresh-air duct and damper and glass screen.
	Wood burner or stove: ______ Output: ______ Btu/hr

WORKSHEET 1D

BUILDING DIMENSIONS
(for Worksheet 2)

CASA AMELIA

Orientation/ Type	Gross Wall Area, ft^2	Window Area, ft^2	Door Area, ft^2	Net Wall Area, ft^2	Perimeter ft
	( ) - [(	)+(	)] = (	).	( )
Total NW					
Total N	26x28 = 208	9	20	179	26
Total NE	28x8 = 224	12	–	212	28
Total E	24.5x8 = 196	51	–	145	24.5
Total SE	34x8 = 272	90	–	182	34
Total W	14x8 = 112	9	–	103	14
Total SW	46x8 = 368	110	–	258	46
Total S CLERES.	26x4 = 104	54	–	50	
Total ~~Trombe~~ W/E CLERES.	2(5)(.5)(25)=125	–	–	125	
Total Air Lock N+W	(2/3)(32)(8)=171	2/3(10)=6.7	2/3(38)=25.3	139	21.5
Total	(1780) - [(342	)+(45	)] = (	1393).	(194)

Roof	Gross Roof Area	(tripleglazed) Skylights	Net Roof Area
	(2070) -	(16) =	(2054)

NIGHT WINDOW INSULATION:

a). DBL. GL. – R-3 → U = 0.27 : E, NE, ~~NW~~ LAUND. = 81

b) DBL. GL. R-2 → U = 0.33 : SE, SW – = 200 SF

c) DBL. GL. R-.5 U = 0.45 : Scler.

d) TRIPLE GL. NO INSUL. N.air, W.air, SK.L. = 77 SF.

WORKSHEET 2

CALCULATION OF BUILDING SKIN CONDUCTANCE

Surface Type	Net Area ft^2		U-value $Btu/hr\text{-}°F\text{-}ft^2$		U x Area $Btu/hr\text{-}°F$*	% of Total
North exterior wall		X		=		
East exterior wall		X		=		
West exterior wall	1393	X	.045	=	63	
South exterior wall		X		=		
South Trombe wall		X		=		
Air lock walls		X		=		
Total Wall Heat Loss					$\boxed{63}$	21
Doors: Entry		X		=		
Patio	45	X	0.4	=	18	
Other		X		=		
North windows R-3	81	X	0.27	=	22	
East windows		X		=		
West windows R-2	200	X	0.33	=	66	
South windows		X		=		
Clerestory windows		X		=		
Sloped skylights	77	X	0.45	=	35	
Horizontal skylights		X		=		
Total Door/Window Heat Loss					$\boxed{141}$	47
Roof	2100	X	.021	=	$\boxed{44}$	15
Floor ** R-8	194	X	0.26	=	$\boxed{50}$	17
Total Building Skin Conductance (add boxed-in values)					298	100

* The values here may be rounded off to whole numbers, as extreme accuracy is not needed.

** Crawlspace = Ah_c (see Figure 4.1)

Slab = F x P (see Table 4.1)

Heated basement = $UA_{wall\ above\ grade} + h_b A_{wall\ below\ grade} + h_c A_{floor}$

WORKSHEET 3

CALCULATION OF INFILTRATION LOAD AND
MODIFIED BUILDING HEAT LOSS COEFFICIENT C_B

House Volume = Gross Floor Area x Ceiling Height =(2070)(8)=18,200
2.5(26)(24.5)
Infiltration Load = Volume x C_p x ACH   ACH = Air Change/Hour

= (18,200) x (0.018) x (0.5)

= 164 Btu/hr-°F

Modified Building Heat Loss Coefficient, C_B

= [Building Skin Conductance* + Infiltration Load]

= 24 [(164) + (298)] = 24 (462)

= 11,100 Btu/D.D.

Gross Heated Floor Area of Building = 2070 ft^2

C_B/A = (11,100) / (2070)
= 5.4 Btu/ft^2-D.D.   D.D. = Degree Days**

* From Worksheet 2.

**"Degree Days" is an indication of the "coldness" of the climate for heating calculations; the degree-day value for a particular day is the difference between the average daily outdoor temperature and 65°F; the data is usually given in monthly and yearly totals. Averaged degree-day data for New Mexico is listed in Table 1-1.

WORKSHEET 4

CALCULATION OF BUILDING THERMAL LOAD PROFILE CASA AMELIA

Modified Building Heat Loss Coefficient C_B from Worksheet 3 = 11,100 Btu/D.D.

Month	Degree Days per Month	x C_B =	Gross Thermal Load, MBtu/month	−	Internal Heat Sources, MBtu/month	=	Net Thermal Load, MBtu/month
Aug.	____	x C_B =	____	−	____	=	____
Sept.	____	x C_B =	____	−	____	=	____
Oct.	100		1.1		1.7		0
Nov.	300		3.3		1.7		1.6
Dec.	520		5.8		1.7		4.0
Jan.	550		6.1		1.7		4.4
Feb.	470		5.2		1.7		3.5
Mar.	360		4.0		1.7		2.3
Apr.	100		1.1		1.7		0
May	2400						15.8
Jun.							
Jul.							

MBtu = Million Btu

WORKSHEET 5

CALCULATION OF SOLAR HEATING CONTRIBUTION CASA AMELIA

Mechanism: DIRECT GAIN SE+SW. GLASS 200(0.85)(0.85) = 144

Net Effective Collector Area: 144 $ft^2 = A_{eff}$

$A_{eff} = A_{gross} \times$ (Frame Shading) $\times$ (Effectiveness, Table 5.1)

Month	CAPE HATTERAS DATA Solar Heat Gain from Figs. 5.2 - 5.4 Btu/Month-$ft^2 \times 10^3$ (1)	Adjustment Factors: Roof Overhang from Worksheet 5B (2)	Adjustment Factors: Off South Orientation: % Reduction from Sec. 5.3 (3)	Solar Heat Absorbed in MBtu/month $A_{eff} \times (1) \times (2) \times (3)$
Aug.	—	—	—	—
Sept	—	—	—	—
Oct.	—	—	—	—
Nov.	32	—	0.8	3.7
Dec.	31	—	0.8	3.6
Jan.	32	—	0.8	3.7
Feb.	29	—	0.85	3.5
Mar.	30	—	0.95	4.1
Apr.	—	—	—	—
May	—	—	—	—
Jun.	—	—	—	—
Jul.	—	—	—	—

WORKSHEET 5

CALCULATION OF SOLAR HEATING CONTRIBUTION CASA AMELIA

Mechanism: DIRECT GAIN CLERESTORY 54(0.85)(0.85)

Net Effective Collector Area: 39.0 $ft^2 = A_{eff}$

$A_{eff} = A_{gross}$ x (Frame Shading) x (Effectiveness, Table 5.1)

Month	Solar Heat Gain from Figs. 5.2 - 5.4 Btu/Month-ft^2 x 10^3 (1)	Adjustment Factors: Roof Overhang from Worksheet 5B (2)	Adjustment Factors: Off South Orientation: % Reduction from Sec. 5.3 (3)	Solar Heat Absorbed in MBtu/month A_{eff} x (1) x (2) x (3)
Aug.	—	—	—	—
Sept	—	—	—	—
Oct.	—	—	—	—
Nov.	32	1.0	—	1.2
Dec.	31	1.0	—	1.2
Jan.	32	1.0	—	1.2
Feb.	29	.91	—	1.0
Mar.	30	.73	—	0.8
Apr.	—	—	—	
May	—	—	—	
Jun.	—	—	—	
Jul.	—	—	—	

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DESIGN CALCULATION PROCEDURE FOR PASSIVE SOLAR HOUSES AT NAVY I--ETC(U)
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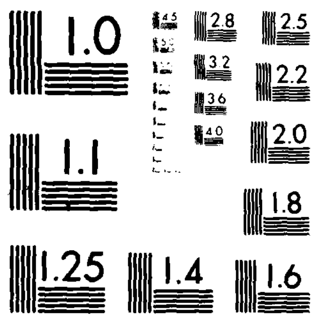


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

WORKSHEET 5B

CALCULATION OF SHADING WITH SOUTH ROOF OVERHANG CASA AMELIA

FOR CLERESTORY WINDOWS

(A) Latitude of building site: 35 °N

(B) Length of summer shadow desired: 4' ft

(C) Size of roof overhang (projection from south wall) from Table 5.2 (directly or interpolated): 2' ft

(D) Height of lower overhang edge from finished floor: 5 ft

(E) Distance from finished floor to top of glazing: 4' ft

(F) Vertical distance from top of glazing to roof overhang: (D) - (E) = 1 ft

(G) Window or glazing height: 3 ft**

Month	Height of Shadow Cast, ft (H) x (C) = (I)	Effective Shadow Length, ft (J) = 2/3 (I)	Window Shading, ft* (K) = (J) - (F)	% Shading, (K)/(G) = (L)	Shading Factor, (M) = 1 - (L)
S	—	—	—	—	—
O	—	—	—	—	—
N	0.68x2=1.36	0.9	0	0	1.
D	0.62x2=1.24	0.82	0	0	1
J	0.68x2=1.36	0.9	0	0	1
F	0.96x2=1.92	1.27	0.27	0.09	0.91
M	1.38x2=2.76	1.82	0.82	0.27	0.73
A	—	—	—	—	—
M	—	—	—	—	—
J	—	—	—	—	—

Enter Column (M) in Column 2, Worksheet 5.

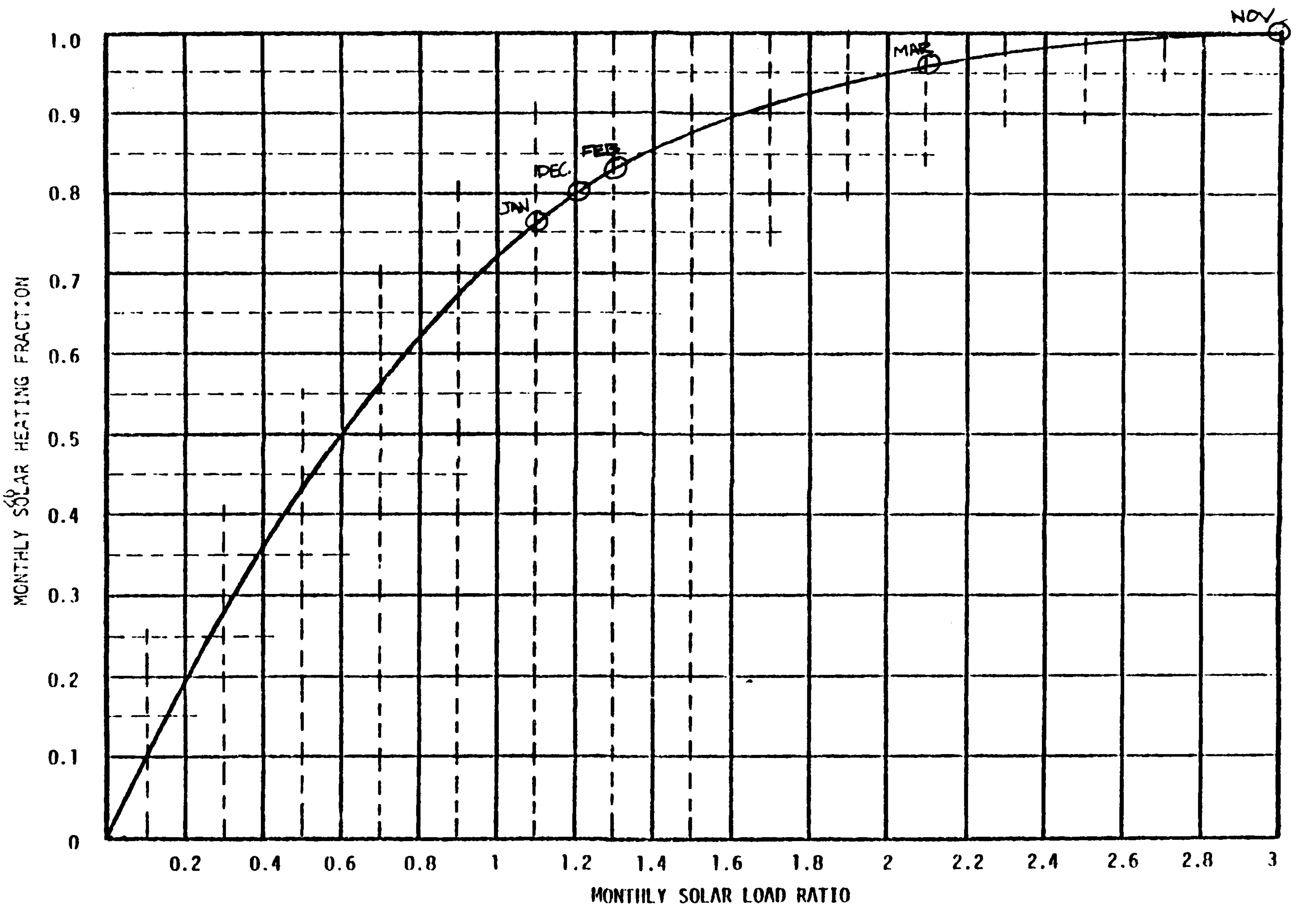
* If (J) - (F) is less than zero, enter zero in Column (K).

** If window (glazing) height varies, a reasonable average can be assumed.

WORKSHEET 6

CALCULATION OF BUILDING AUXILIARY LOAD PROFILE

Month	Net Thermal Load (from Worksheet 4) (A)	Total Solar Heat Gain (from Worksheet 5) (B)	Solar Load Ratio (SLR) (B) ÷ (A) (C)	Solar Heating Fraction (SHF) (from Fig. 5.7) (D)	Solar Heating Contrib. (D) x (A) (E)	Auxiliary Load Profile (A) - (E) (F)
Aug.	—	—	—	—	—	—
Sept.	—	—	—	—	—	—
Oct.	—	—	—	—	—	—
Nov.	1.6	4.9	3	1	1.6	0
Dec.	4.0	4.8	1.2	0.8	3.2	0.8
Jan.	4.4	4.9	1.1	0.76	3.3	1.1
Feb.	3.5	4.5	1.29	0.82	2.9	0.6
Mar.	2.3	4.9	2.13	0.96	2.2	0.1
Apr.	—	—	—	—	—	—
May	—	—	—	—	—	—
Jun.	—	—	—	—	—	—
Jul.	—	—	—	—	—	—
TOTAL	15.8 MBtu				13.2 MBtu	2.6 MBtu



Monthly Passive Solar Heating Estimator

WORKSHEET 7

GLAZING AND STORAGE CALCULATIONS — CASA AMELIA

Daily Maximum Solar Heat Gain: 1375 BTU/FT² Jan.

Room	EFFECTIVE OR South Glazing ft²	Floor Area ft²	Designed Storage ft³	Storage Volume per 100 ft² of Glazing ft³	Temp. Swing °F
.....					
MR.BR.	(0.73)(54)= 39		125 WALL (16" th)	325	17°
BR.2	26		125 WALL	480	12°
BR.3	18		80 WALL	440	13°
L.R.	54		90 sunwall, 165 shade, 75 FLOOR } 330	610	9°
BATH	9		10 FLOOR/WALL	110	25°+
DIN/KITCH	54		180 WALLS, 70 KITCH + HALL FLOORS	465	13°
.....					
TOTAL			920		

Check for temperature drop during a completely cloudy day (24-hour period):

$$\text{Maximum } \Delta T = \frac{\text{Net January Thermal Load*}/31}{\text{Total Volume} \times \text{(Heat Capacity of Storage Material)**}}$$

$$\Delta T = \frac{(6{,}100{,}000)}{31\ (26)\ (920)} = \underline{8°}\ °F$$

*From Worksheet 4.
**From Table 6.2.

WORKSHEET 8A

CALCULATIONS FOR REFERENCE BUILDING

Building Location: WILMINGTON, N.C. Zone: A

Floor Area: 2150 ft^2 = (_____ $ft)^2$; Perimeter = 194 ft;

S. Window Area = (0.15)(A)÷4 = 80 ft^2;

Effective Window Area = ½(80)(.85)(.85) = 29 ft^2

Building Skin Conductance (Btu/hr-°F):

Total Walls:	U-Value x Area = (.08) x (1190) =	95
Total Windows and Doors:	U-Value x Area = (.68) x (342) =	233
Roof:	U-Value x Area = (.045) x (2150) =	97
Floor: (See Section 4.1) (R=11) (CRAWLSPACE)	= (.051) x (2150) =	110
	TOTAL	$\boxed{535}$

Infiltration: Volume x C_p x ACH = (17200) x (0.018) x 1 = $\boxed{310}$

Modified Building Heat Loss Coefficient C_B

= 24 (Skin Conductance + Infiltration) = 24[($\underbrace{535 + 310}_{845}$)] = $\boxed{20,304}$

C_B/A = $\boxed{9.4}$ Btu/D.D.-ft^2

Heat Load Calculations (MBtu): Gross Heating Load minus Solar Heat Absorbed is equal to Net Heating Load

Month	Degree Days	Gross Heating Load	Solar Gain	Solar Heat Absorbed	Net Heating Load
Aug.	—	—	—	—	—
Sept.	—	—	—	—	—
Oct.	100	2.0	33	1.0	1.0
Nov.	300	6.1	32	0.9	5.2
Dec.	520	10.6	31	0.9	9.7
Jan.	550	11.2	32	0.9	10.3
Feb.	470	9.5	29	0.8	8.
Mar.	360	7.3	30	0.9	6.4
Apr.	100	2.0	25	0.7	1.3
May	—	—	—	—	—
Jun.	—	—	—	—	—
Jul.	—	—	—	—	—

WORKSHEET 8B

HEAT SAVINGS CALCULATIONS FOR PASSIVE DESIGN* CASA AMELIA

Month	Reference Bldg. Heating Load	Passive Solar Building Aux. Load	Gross Heat Saved	Energy Used For Fans in Passive Home, kWh x 0.0034	Net Energy Saved	Cost of Energy Saved: ELECTRICITY: cents/kWh x 2.93 GAS: $/therm x 1.7 ** OIL: $/gal x 14.4 *** WOOD: $/cord x 0.11 **** =17.6 $/MBtu x Net Savings =			
	MBtu/mo.	MBtu/mo.	MBtu	MBtu	MBtu	$			
						EL	GAS	OIL	WOOD
Aug.	( ) -	( ) =							
Sept.									
Oct.	1.0	—	1.0						
Nov.	5.2	—	5.2						
Dec.	9.7	0.8	8.9						
Jan.	10.3	1.	9.3						
Feb.	8.7	0.6	8.1						
Mar.	6.4	0.1	6.3						
Apr.	1.3	0	1.3						
May									
Jun.							@$7.00	@ $1.00	@$80.00
Jul.						@6¢/kWH	per 1000 ft³	per gallon	per cord
TOTAL	42.6	2.5	40.1			$705	511	577	353

*Does not include savings for solar water heating (or summer cooling).

**50% efficiency.

*** 1 MBtu = 7.2 gal. heating oil, 50% efficiency.

****Average of 20 MBtu per cord of wood depending on type [15] and 45% efficiency.

Discussion of Results

CASA AMELIA was originally designed for a southern New Mexico climate with 3400 heating degree days. The less favorable solar insolation of the East Coast (Wilmington, NC) location is counterbalanced by the milder winter temperatures. To improve natural ventilation, one window in the laundry room was moved from W to N. The bathrooms must all be equipped with a ventilating fan to the exterior in order to reduce humidity levels in the summer.

Solar heat gains may be slightly less than indicated by the calculations, since the 4-ft roof overhang on the SW side was not taken into account. It is highly recommended that deciduous shade trees be planted near the house on the SE and SW side to give summer cooling without decreasing natural ventilation. The garden gate in the W wing wall must be of open grille work, not of solid wood. At least some of the clearstory windows should be operable.

Because the bedrooms will not be heated with the fireplace, the auxiliary load will most likely be less than that indicated by the calculations and can very easily be supplied by the heat-circulating fireplace. The bathrooms should have a separate heat source, i.e. heat lamp. Heat storage mass could possibly be reduced somewhat in this humid climate, i.e. the tile-on-slab floors could be replaced with a wood parquet floor over joists/crawlspace. The crawlspace should be vented in the summer but closed-off tightly in the winter.

The skew orientation for this design was originally chosen because of an outstanding view to the SW and other particular lot requirements. If adequate shading is provided, this orientation should not be a problem in the Wilmington area, especially if summer breezes at the site come from a predominantly SW direction. Louvered shutters will help to keep summer sun out, yet will allow natural ventilation. Because of the mild climate, winter energy savings are not as large as for the New England design (see Vol. I); however, savings due to a reduced summer cooling load and for water heating should be quite substantial (especially since summer cooling requires peak load electricity).

ATTACHMENT

SET OF WORKSHEET BLANKS FOR XEROXING

A set of loose-leaf worksheets is provided here for making xerox copies; the design of a passive house from the initial concept to final drawings usually requires at least three sets.

WORKSHEET 1A

DESIGN INFORMATION

1. Location of building: ______________ Altitude: ______________
2. Building type (one or two story, split-level, etc.): ______________
3. Roof shape: ______________
4. Lot size: ______________ Special features: ______________
5. Lot orientation (in which direction will the house face the street?): ______
6. Building setbacks (check with local codes): ______________
7. Zoning restrictions and covenants: ______________
8. Lot access: ______________
9. Utility access: ______________
10. Lot slope, water runoff (erosion?), berming: ______________
11. Predominant direction of winter wind: ______ Velocity: ____ mph average
12. Predominant direction of summer breeze: ______ Velocity: ____ mph average
13. Direction of best view: ______________
14. Direction of worst view: ______________
15. Shading from neighboring houses, trees, etc.: ______________
16. Approximate floor area: ______________ Heated basement? ______________
17. Number of occupants: ______________
18. Number of bedrooms, baths: ______________
19. Other living spaces wanted: ______________
20. Life style of occupants and special needs (i.e. play area for children, space for entertaining, hobbies; space used during day, evening; special storage requirements; handicaps): ______________
21. Preferred patio location, other outdoor recreation areas: ______________
22. Occupants like the following features: ______________
23. Occupants dislike the following features: ______________

WORKSHEET 1B

SPACE RELATIONSHP DIAGRAM

Floor area: ______________ sq. ft.

Sketch the location of the main entry and the living, cooking, eating and sleeping areas; then mark the major wind directions and use baths, utility, storage areas and garage as buffer zones against winter winds and summer heat. Indicate the zoning barrier (■■■) and tentatively mark the location of auxiliary heat sources (✷). Areas thus marked will need to be designed so that they can be completed closed off from the remaining sections of the house during periods when auxiliary heating is necessary. Finally, show the direction(s) of the best view (and, optionally, undersirable views which will need to be screened).

WORKSHEET 1C

ADDITIONAL INFORMATION AND CHECKLIST FOR ENERGY CONSERVATION

- Building orientation is within 5° E or W of South.
- Major axis runs east-west.
- Windbreaks are provided against winter and spring storms.
- Windows are of double or triple-glazed wood-frame (or equivalent) casement, single- or double-hung type? ______
- Window areas to the north, east and west are minimized.
- Windows allow sufficient natural summer ventilation.
- Windows are insulated at night by (insulated drapes, shades, interior or exterior shutters): ______
- Passive solar mechanisms included in the design are: ______
- Storage mass is located at: ______
- Are fans used for heat distribution: ______ Where? ______
- Is there a solar greenhouse? ______
- Are there well-lighted spaces in the house for plants? ______
- Can sources of humidity in the house be vented easily? ______
- Is the main entry an air lock in the winter or breezeway in the summer? ______ Do other entries have air locks or storm doors? ______
- Can heated living areas be closed-off from sleeping areas? ______
- What type backup heater is planned? ______

- Will a solar water heater be used? ______ What type? ______
- Solar tank location, size: ______
- Collector location: ______ Type: ______ Area needed: ______
- Heat exchanger(s): ______
- Collector slope (approximately equal to latitude +10° is best): ______

- Backup water heater, type, size, fuel: ______
- Energy-efficient applicances to be used are: ______
- Fluorescent lights are to be used in: ______
- Fireplace has chimney on interior wall and is equipped with fresh-air duct and damper and glass screen.
- Wood burner or stove: ______ Output: ______ Btu/hr

WORKSHEET 1D BUILDING DIMENSIONS (for Worksheet 2)		
Orientation/ Type	Gross Wall Area, ft^2 — Window Area, ft^2 — Door — Net Wall Area, ft^2	Perimeter ft
	( ) - [( )+( )] = ( ).	( )
Total NW Total N Total NE Total E Total SE Total W Total SW Total S Total Trombe Total Air Lock		
Total	( ) - [( )+( )] = ( ).	( )
Roof	Gross Roof Area — Skylights — Net Roof Area ( ) - ( ) = ( )	

WORKSHEET 2

CALCULATION OF BUILDING SKIN CONDUCTANCE

Surface Type	Net Area ft^2		U-value $Btu/hr\text{-}°F\text{-}ft^2$		U x Area $Btu/hr\text{-}°F$*	% of Total
North exterior wall	____	X	____	=	____	
East exterior wall	____	X	____	=	____	
West exterior wall	____	X	____	=	____	
South exterior wall	____	X	____	=	____	
South Trombe wall	____	X	____	=	____	
Air lock walls	____	X	____	=	____	
Total Wall Heat Loss					$\boxed{}$	____
Doors: Entry	____	X	____	=	____	
Patio	____	X	____	=	____	
Other	____	X	____	=	____	
North windows	____	X	____	=	____	
East windows	____	X	____	=	____	
West windows	____	X	____	=	____	
South windows	____	X	____	=	____	
Clerestory windows	____	X	____	=	____	
Sloped skylights	____	X	____	=	____	
Horizontal skylights	____	X	____	=	____	
Total Door/Window Heat Loss					$\boxed{}$	____
Roof	____	X	____	=	$\boxed{}$	____
Floor **	____	X	____	=	$\boxed{}$	____
Total Building Skin Conductance (add boxed-in values)					____	100

* The values here may be rounded off to whole numbers, as extreme accuracy is not needed.

** Crawlspace = Ah_c (see Figure 4.1)

Slab = F x P (see Table 4.1)

Heated basement = $UA_{\text{wall above grade}} + h_bA_{\text{wall below grade}} + h_cA_{\text{floor}}$

WORKSHEET 3

CALCULATION OF INFILTRATION LOAD AND
MODIFIED BUILDING HEAT LOSS COEFFICIENT C_B

House Volume = Gross Floor Area x Ceiling Height =( )( )=____

Infiltration Load = Volume x C_p x ACH   ACH = Air Change/Hour

= ( ) x ( ) x ( )

= _______ Btu/hr-°F

Modified Building Heat Loss Coefficient, C_B

$$= \left[\begin{matrix}\text{Building Skin} \\ \text{Conductance}^*\end{matrix} + \begin{matrix}\text{Infiltration} \\ \text{Load}\end{matrix}\right]$$

= 24 [( ) + ( )] = 24 ( )

= ____________________ Btu/D.D.

Gross Heated Floor Area of Building = ________ ft^2

C_B/A = ( ) / ( )

= ____________ Btu/ft^2-D.D.   D.D. = Degree Days**

* From Worksheet 2.

**"Degree Days" is an indication of the "coldness" of the climate for heating calculations; the degree-day value for a particular day is the difference between the average daily outdoor temperature and 65°F; the data is usually given in monthly and yearly totals. Averaged degree-day data for New Mexico is listed in Table 1-1.

WORKSHEET 4

CALCULATION OF BUILDING THERMAL LOAD PROFILE

Modified Building Heat Loss Coefficient C_B from Worksheet 3 = _____ Btu/D.D.

Month	Degree Days per Month	$\times C_B$	=	Gross Thermal Load, MBtu/month	−	Internal Heat Sources, MBtu/month	=	Net Thermal Load, MBtu/month
Aug.	_____	$\times C_B$	=	_____	−	_____	=	_____
Sept.	_____	$\times C_B$	=	_____	−	_____	=	_____
Oct.								
Nov.								
Dec.								
Jan.								
Feb.								
Mar.								
Apr.								
May								
Jun.								
Jul.								

MBtu = Million Btu

WORKSHEET 5

CALCULATION OF SOLAR HEATING CONTRIBUTION

Mechanism: ______________________________

Net Effective Collector Area: __________ $ft^2 = A_{eff}$

$A_{eff} = A_{gross}$ x (Frame Shading) x (Effectiveness, Table 5.1)

Month	Solar Heat Gain from Figs. 5.2 - 5.4 Btu/Month-ft^2 x 10^3 (1)	Adjustment Factors: Roof Overhang from Worksheet 5B (2)	Adjustment Factors: Off South Orientation: % Reduction from Sec. 5.3 (3)	Solar Heat Absorbed in MBtu/month A_{eff} x (1) x (2) x (3)
Aug.				
Sept				
Oct.				
Nov.				
Dec.				
Jan.				
Feb.				
Mar.				
Apr.				
May				
Jun.				
Jul.				

WORKSHEET 5A

ADJUSTED NET SOLAR GREENHOUSE HEAT GAIN

Month	Solar Heat Gain Absorbed (from Worksheet 5 of Greenhouse Calculations)		Monthly Heat Loss (Net Thermal Load) from Worksheet 4* MBtu/month		Net Heat Gain MBtu/month x Adjustment Factor ( )	=	Adjusted Net Solar Greenhouse Heat Gain
Aug.	________	-	________	=	________		________
Sept.							
Oct.							
Nov.							
Dec.							
Jan.							
Feb.							
Mar.							
Apr.							
May							
Jun.							
Jul.							

*For greenhouse heat loss to the outside only.

WORKSHEET 5B

CALCULATION OF SHADING WITH SOUTH ROOF OVERHANG

(A) Latitude of building site: _____ °N

(B) Length of summer shadow desired: _______ ft

(C) Size of roof overhang (projection from south wall)
from Table 5.2 (directly or interpolated): ___________ ft

(D) Height of lower overhang edge from finished floor: ____________ ft

(E) Distance from finished floor to top of glazing: __________ ft

(F) Vertical distance from top of glazing to roof overhang:
(D) - (E) = __________ ft

(G) Window or glazing height: ________ ft**

Month	Height of Shadow Cast, ft (H) x (C) = (I)	Effective Shadow Length, ft (J) = 2/3 (I)	Window Shading, ft* (K) = (J) - (F)	% Shading, (K)/(G) = (L)	Shading Factor, (M) = 1 - (L)
S					
O					
N					
D					
J					
F					
M					
A					
M					
J					

Enter Column (M) in Column 2, Worksheet 5.

* If (J) - (F) is less than zero, enter zero in Column (K).

** If window (glazing) height varies, a reasonable average can be assumed.

WORKSHEET 6

CALCULATION OF BUILDING AUXILIARY LOAD PROFILE

Month	Net Thermal Load (from Worksheet 4) (A)	Total Solar Heat Gain (from Worksheet 5) (B)	Solar Load Ratio (SLR) (B) ÷ (A) (C)	Solar Heating Fraction (SHF) (from Fig. 5.7) (D)	Solar Heating Contrib. (D) x (A) (E)	Auxiliary Load Profile (A) - (E) (F)
Aug.						
Sept.						
Oct.						
Nov.						
Dec.						
Jan.						
Feb.						
Mar.						
Apr.						
May						
Jun.						
Jul.						
TOTAL	MBtu				MBtu	MBtu

WORKSHEET 7

GLAZING AND STORAGE CALCULATIONS

Daily Maximum Solar Heat Gain:________

Room	South Glazing ft^2	Floor Area ft^2	Designed Storage ft^3	Storage Volume per 100 ft^2 of Glazing ft^3	Temp. Swing °F
.....					
.....					
.....					
.....					
.....					
.....					
.....					
.....					
	____	____	____	____	
TOTAL	====	====	====	====	

Check for temperature drop during a completely cloudy day (24-hour period):

$$\text{Maximum } \Delta T = \frac{\text{Net January Thermal Load*/31}}{\text{Total Volume x (Heat Capacity of Storage Material)**}}$$

$$\Delta T = \frac{(\qquad\qquad)}{31\ (\qquad)\ (\qquad)} = \underline{\qquad\qquad}\ °F$$

*From Worksheet 4.
**From Table 6.2.

WORKSHEET 8A

CALCULATIONS FOR REFERENCE BUILDING

Building Location: Zone:

Floor Area:______ft^2 = (______ft$)^2$; Perimeter = _____ft;

S. Window Area = (0.1)(A)+4 = _______ft^2;

Effective Window Area = ½( )( )( ) = _____ft^2

Building Skin Conductance (Btu/hr-°F):

Total Walls:	U-Value x Area = ( )x( )	= _____
Total Windows and Doors:	U-Value x Area = ( )x( )	= _____
Roof:	U-Value x Area = ( )x( )	= _____
Floor: (See Section 4.1)	= ( )x( )	= _____
	TOTAL	

Infiltration: Volume x C_p x ACH = ( ) x ( ) x 1 =

Modified Building Heat Loss Coefficient C_B

= 24 (Skin Conductance + Infiltration) = 24[(+)] =

C_B/A = Btu/D.D.-ft^2

Heat Load Calculations(MBtu): Gross Heating Load minus Solar Heat Absorbed is equal to Net Heating Load

Month	Degree Days	Gross Heating Load	Solar Gain	Solar Heat Absorbed	Net Heating Load
Aug.					
Sept.					
Oct.					
Nov.					
Dec.					
Jan.					
Feb.					
Mar.					
Apr.					
May					
Jun.					
Jul.					

WORKSHEET 8B

HEAT SAVINGS CALCULATIONS FOR PASSIVE DESIGN*

Month	Reference Bldg. Heating Load	Passive Solar Building Aux. Load	Gross Heat Saved	Parasitic Power (See Footnote), kWh x 0.0034	Net Energy Saved	Cost of Energy Saved: ELECTRICITY: cents/kWh x 2.93; GAS: $/MCF x 1.7 **; OIL: $/gal x 14.4 ***; WOOD: $/cord x 0.11 ****; =____ $/MBtu x Net Savings =			
	MBtu/mo.	MBtu/mo.	MBtu	MBtu	MBtu	$			
						EL	GAS	OIL	WOOD
Aug.	( ) -	( ) =							
Sept.									
Oct.									
Nov.									
Dec.									
Jan.									
Feb.									
Mar.									
Apr.									
May									
Jun.									
Jul.									
TOTAL									

*Does not include savings for solar water heating (or summer cooling).

**60% efficiency.

*** 1 MBtu = 7.2 gal. heating oil, 50% efficiency.

****Average of 20 MBtu per cord of wood depending on type [15] and 45% efficiency.

Add electricity needed to run the conventional furnace; substract the electricity needed to operate fans in the passive design.

DATE
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